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MAINTENANCE IMPROVEMENT:
AN ANALYSIS APPROACH
INCLUDING INFERENTIAL TECHNIQUES

VOLUME II

TECHNICAL REPORT

Milton Clyman
Philip S. Grenetz
Richard S. Shultz

Approved for public release: distribution unlimited

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Prepared for:

Department of Defense
OASD (MRA&L)
Pentagon - Room 2B323
Washington, D.C. 20301
Attention: Lt. Col. Roger Grossel

1745 JEFFERSON DAVIS HIGHWAY
ARLINGTON, VIRGINIA 22202
(703) 521-1050

955 LOUIS DRIVE
WARMINSTER, PA. 18974
(215) 674-8022

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This final report, contained in four volumes, presents the results of research into assessing the economic (cost and down-time) impact of Potentially Avoidable Maintenance actions for selected Naval aircraft subsystems. Maintenance actions requiring no repair and those resulting in induced defects and failure-to-correct were identified. Specific high-driver two-digit Work Unit Codes were analyzed for the F-14A Fire Control, S-3A Bombing Navigation, S-3A Landing Gear, and A-7E Bombing Navigation.

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20. The content of the respective volumes of this report are as follows:

Volume I - Overview

Volume II - Technical Report - includes the research methodology, results, and recommendations. The Interim Feasibility Report is an appendix to Volume II.

Volume III - Detailed Technical Data - includes the computer-generated input information tables and output data tables which form the foundation for the results contained in Volume II.

Volume IV - Software Manual - includes the logic used to develop software for generating the tables in Volume III, user instructions, and a complete listing of programs that were executed to arrive at the tables.

For the respective aircraft studied, only data from squadrons within CNAL were utilized. These results were used to project the cost and down-time impact of Potentially Avoidable Maintenance for the whole fleet of the subsystems studied.

The study made a coarse evaluation of Built-In Test effectiveness for one subsystem. Fault isolation capability regarding Shop Replaceable Assemblies was also assessed.

The study concluded that Potentially Avoidable Maintenance contributes significantly to maintenance costs and aircraft down-time, and recommends actions to identify and control the causes.

VOLUME II - TECHNICAL REPORT

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FOREWORD

This Final Report was prepared for the Department of Defense, OASD (MRA&L) by Information Spectrum, Inc., Warminster, PA, under Contract No. MDA903-78-C-0176. (Contract Period 27 December 1977 through 15 March 1979.)

This report describes work covered during Phase II (17 April 1978 to 15 March 1979) and consists of four volumes:

Volume I - Overview

Volume II - Technical Report

including the Phase I Feasibility Study (27 December 1977 to 7 April 1978) as an Appendix

Volume III - Detailed Supporting Data

Volume IV - Software Manual

The principal contributor to this volume was Mr. Philip S. Grenetz, Senior Systems Analyst; assisted by Mr. Richard Shultz, Director of Reliability and Maintainability; under the direction of Mr. Milton Clyman, Executive Vice President.

The contractors report number for this volume is W-7958-02(B).

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The authors of this study wish to acknowledge the support and cooperation of the many government participants in the research effort. During the course of the study, the authors had the benefit of numerous constructive comments and review from persons in the Office of the Assistant Secretary of Defense (MRA&L), in particular Mr. Russell Shorey, Mr. Martin Meth, Lt. Col. Roger Grossel and Lt. Col. Donald Tetmeyer.

The Navy furnished key support and information necessary for the conduct of the research. In particular we are indebted to Capt. W. J. Oslun, Office of the Chief of Naval Operations (CNO-514), for providing access to necessary data sources. Also within the Navy we wish to acknowledge the cooperation of Mr. Duncan P. Dixon, NWESA 44N, for making available AMPAS data tapes, and answering inquiries regarding these tapes; and Mr. William Smith of the Naval Air Technical Services Facility for providing access to equipment technical and maintenance documents.

1.0 INTRODUCTION

This Final Report for the Maintenance Improvement Study is submitted in compliance with Contract No. MDA903-78-C-0176, dated 23 Jan 1978, Delivery Item No. 0002AC. This report documents a study conducted for the OASD(MRA&L), to determine the potential economic benefit achievable by improving the maintenance process for aircraft weapon systems. The contract period of performance of this study was 27 December 1977 through 15 March 1979.

1.1 Purpose

Specifically, the occurrences of potentially avoidable unscheduled maintenance actions were to be identified and their cost and down-time impact assessed. The term "unscheduled" refers to corrective or No-Repairs-Required actions, whether initiated during scheduled or unscheduled maintenance. Potentially avoidable unscheduled maintenance actions are divided into several categories as defined in Section 1.4 of this report. The relationship between Built-In Test (BIT) on a selected weapon system, and failure diagnosis in general, to the problem of Potentially Avoidable Maintenance (PAM) was also to be analyzed.

1.2 Feasibility Study

The effort proceeded in two phases. Phase I was a feasibility study which verified the existence of the problem and quantified one category thereof, i.e., No-Repairs-Required actions[1]. The feasibility study resulted in a conceptual technique for detecting the occurrence of PAM actions which are not directly reported. The

Interim Feasibility Study Report is provided as an appendix to this Volume of the Final Report.

Specific Naval aircraft Type/Model/Series (T/M/S), Work Unit Codes (WUCs), and squadrons were selected, as well as requisite data sources, for application of the technique. The study then proceeded into Phase II.

1.3 Scope

The Commander of Naval Air Force, U.S. Atlantic Fleet (CNAL) squadrons of the F-14A, S-3A, and the A-7E were the subject aircraft and squadrons selected for the study. Fiscal Year 1977 was chosen as the sample time interval because it was the latest full fiscal year for which data were available. The following WUCs were selected as the subject WUCs of the respective aircraft:

F-14A	74	FIRE CONTROL
S-3A	73	BOMBING NAVIGATION
S-3A	13	LANDING GEAR
A-7E	73	BOMBING NAVIGATION

Avionics was generally found, by the feasibility study, to be the greatest contributor to No-Repairs-Required actions. To balance the picture and provide a frame of reference for evaluating avionics maintenance, a non-avionic WUC was included in the study. The landing gear (WUC 13) of the S-3A was selected because it was the greatest non-avionics contributor on the S-3A and, proportionately, the greatest non-avionics contributor on any of the selected aircraft. WUC 73 of the S-3A was selected as subject of the BIT performance evaluation.

1.4 Problem and Cost Classification

The specific categories of Potentially Avoidable Maintenance addressed by the study are as depicted in Table 1. These categories are defined as follows:

— No-Repairs-Required

All maintenance actions resulting in Action Taken Code (ATC) A reported on the Maintenance Action Form (MAF).

— Potentially Avoidable Cannibalization

Cannibalizations performed to replace equipments falsely removed.

— Potentially Avoidable Access

Remove-and-reinstall actions performed to facilitate access to equipments which are falsely removed.

— Failure-To-Acknowledge

Rejection, as invalid complaints, of legitimate discrepancies reported by operations personnel.

— Failure-To-Diagnose

No-Repairs-Required actions resulting from inefficient O-Level troubleshooting procedures, i.e., "shotgun" and trial-and-error. These involve multiple removals of functionally related equipments, simultaneous or over a period of time, and transfers to a higher maintenance level, in order to repair the aircraft.

— Failure-To-Correct

Repeated (one or more) unsuccessful attempts (separate maintenance actions) to correct a defect.

— Reported Induced Defect

Corrective actions reported on the MAF as being induced by maintenance, transportation, or handling.

— Internally Induced Defect

Defects induced on a piece of equipment during the maintenance (scheduled or unscheduled) of the same equipment.

TABLE 1. POTENTIALLY AVOIDABLE MAINTENANCE CATEGORIES

NO-REPAIRS-REQUIRED ACTIONS		
	O-LEVEL	
		FAILURE-TO-ACKNOWLEDGE
		OTHER
	I-LEVEL	
		FAILURE-TO-DIAGNOSE
		OTHER
FAILURE-TO-CORRECT		
INDUCED DEFECT ACTIONS		
	REPORTED	
	INTERNALLY DURING CORRECTIVE MAINTENANCE	
	EXTERNALLY DURING CORRECTIVE MAINTENANCE	
	INTERNALLY DURING NON-CORRECTIVE MAINTENANCE	
	EXTERNALLY DURING NON-CORRECTIVE MAINTENANCE	

— <u>Externally Induced Defect</u>

Defects induced on a piece of equipment during the maintenance (scheduled or unscheduled) of a physically related piece of equipment.

Use of the terms Corrective and Non-Corrective in connection with Induced Defect indicates the type of action which led to the defect.

In addition, the No-Repairs-Required actions resulting from trial-and-error fault isolation to the Shop Replaceable Assembly (SRA) and sub-SRA level were quantified and will be denoted as Failure-To-Fault-Isolate.

It should be noted that the vast majority of occurrences of ATC A (i.e., No-Repairs-Required) are associated with How Malfunctioned Code (HMC) 799, which indicates that no defect was discovered. A few occurrences are reported in conjunction with HMCs that indicate either operator error or adjustments performed, but not essential, such as the following:

127 — ADJUSTMENT OR ALIGNMENT IMPROPER
281 — HIGH OUTPUT, READING, OR VALUE
282 — LOW OUTPUT, READING, OR VALUE
437 — IMPROPERLY POSITIONED/SELECTED, OR OTHER OPERATOR ERROR

Therefore, all No-Repairs-Required actions (not just "A 799"s) were considered individually to be unproductive maintenance actions.

The specific elements of cost by which the impact of PAM actions was measured are as presented in Table 2. The term "cost" is used here in the generic sense to include monetary cost and loss of utility, i.e., readiness. The organization of the cost breakdown structure is based on that provided by an LMI Study on Aircraft Operating & Support Costs, and the definitions are as specified therein[2].

TABLE 2. COST ELEMENT STRUCTURE

OPERATING AND SUPPORT COST
BELOW-DEPOT MAINTENANCE
O&I LEVEL LABOR
O&I LEVEL MATERIAL
REPLENISHMENT SPARES
DEPOT MAINTENANCE
LABOR
MATERIAL
SECOND DESTINATION TRANSPORTATION
NOT OPERATIONALLY READY (NOR) TIME
DUE TO "UNSCHEDULED" MAINTENANCE (NORMU)
AWAITING MAINTENANCE (AWM)
PURE (NORMU(P))
DUE TO SUPPLY (NORS)

and the latter serves to initiate a new search for subsequent

1.5 Viewpoint of Study

It is anticipated that the results of this study will ultimately lead to the establishment of design guidelines and procurement and logistics policies/procedures for making economically sound investments in new airborne weapon system programs with respect to reduction of Potentially Avoidable Maintenance.

Indeed, it is for this reason that the modern fighter and search aircraft were selected for study. Unfortunately, several years of experience with new aircraft may be required for the maintenance process to achieve a stable level of efficiency. Therefore, to remove from the results of the study the bias created by the recent introduction of the F-14A and S-3A into operation, the more mature attack aircraft, the A-7E, was also selected,

To further orient the reader, it should be noted that it would be unfair and inaccurate to interpret the Potentially Avoidable Maintenance uncovered by this study as exclusively the fault of careless or unskilled maintenance technicians. Many No-Repairs-Required actions, for instance, may result from multiple removals/replacements of Weapon Replaceable Assemblies (WRAs) performed to effect a quick repair of the weapon system so as to satisfy a mission requirement. Similarly, many multiple removals/replacements of Shop Replaceable Assemblies (SRAs) may be performed to effect a quick repair of a WRA. These actions may represent a significant proportion of No-Repairs-Required actions. In addition, many such actions may result from intermittent failures, failures which can't be duplicated in a maintenance environment,

false BIT indications, and unwarranted complaints of operations personnel.

The inducement by maintenance technicians of equipment damage caused during maintenance of the same or another equipment may result, as least partially, from tight spaces, difficult access, and poor placement (from the maintenance viewpoint).

It may be possible to minimize the diagnosis problem by improving BIT capability. The induced-defect problem might be partially solved by locating equipments in the airplane according to frequency of removal.

1.6 Organization of Report

The remainder of the Volume is organized into the following major sections:

2.0 METHODOLOGY
3.0 RESULTS
4.0 RECOMMENDATIONS

The presentation of results follows the description of methodology because interpretation of the results depends on a basic understanding of the analytical technique and an appreciation of certain subtle aspects thereof.

2.0 METHODOLOGY

The analytical technique described conceptually in the Feasibility Report for tracing Potentially Avoidable Maintenance actions was adopted for implementation in Phase II[1]. This technique was developed into a set of algorithms which could be expected to identify, by inference, many occurrences of PAM of each type as defined in Section 1.4. The algorithms were then converted to a system of computer programs called PAM Assessment System (PAMAS). It was coded in the COBOL language and is documented in Volume IV of this Final Report.

The need to use an inferential technique resulted from the fact that both human nature and the structure of the Maintenance Data Reporting (MDR) system prevent the direct reporting of PAM actions. Human nature contributes to this problem by the reluctance to report HMCs indicating induced defects.

The reporting system contributes in the following ways. A piece of equipment in the maintenance cycle flows from the aircraft or Organizational (O)-Level maintenance and, where appropriate, to Intermediate (I)-Level maintenance. If the equipment is transferred to the I Level, it is either repaired, returned as a No-Repairs-Required action, transferred to the depot, or discarded. The depot would either repair the equipment, discard it, or return it as a no-defect action. Except under special circumstances, the depot will return it to the supply system which will return it to any Intermediate Maintenance Activity (IMA). If the I Level returns an equipment to base supply, it

may be installed at a later date on any aircraft served by that IMA.

The reporting system is not designed to track the progress of an equipment through all of the paths in this network. There is no way within the existing MDR system to identify no-defect actions at the depot. This category was, therefore, excluded from the present study.

The Maintenance Material and Management (3M) MDR system compounds the tracking problem in the following way. Only one part serial number is carried through the system from the MAF. On the MAF for a remove-and-replace action, entries are provided for the serial numbers of both the removed and replacement items, but only the serial number of the removed item is considered by the 3M system. Thus, the installation date is not directly discernible. This date initiates a time interval which could be scanned for a subsequent related maintenance action.

Another drawback of the reporting system, from the standpoint of its application to this study, is its characteristic of recording successive passes through the maintenance cycle, whether or not related, as separate maintenance actions. For instance, the failure to correct a defect on the first attempt may be expected to result in at least one additional action, representing further attempts to repair. Such subsequent actions would have different identifying Job Control Numbers (JCNs). Another example is the inadvertent damage occurring to a piece of equipment during a maintenance action, undiscovered until a later date. This also

display, respectively, physical and functional

will result in an additional repair action with a different identifying JCN.

The final drawback of the reporting system, as applied to this study, is its failure to identify, with one JCN, actions occurring on different, but related, equipments. For instance, if several related WRAs are removed over a period of time in an attempt to troubleshoot a discrepancy, separate JCNs are assigned, one for each Work Unit Code (WUC). If during the removal or installation of one WRA, damage is inadvertently induced on other WRAs, the corrective actions on the damaged equipments are all assigned individual JCNs.

In contrast to the PAMAS analysis, the BIT evaluation of the S-3A was performed at a gross level. The performance of BIT on WUC 73 as a whole was assessed via computation of various performance parameters. The Failure-To-Fault-Isolate analysis was also conducted at a gross level, but it was conducted for all two-digit Subject WUCs (SWUCs). The following paragraphs describe the PAMAS analytical logic, the BIT evaluation technique, and the Failure-To-Fault-Isolate analysis.

2.1 Analytical Logic

The following paragraphs describe the PAMAS algorithms and the basic data-processing considerations required to implement them.

2.1.1 Pre-Processing

The individual maintenance action data required to execute the search algorithms are provided, in the form of magnetic tape,

for Report Nos. PTX-438D, PTX-438E, and PTX-438P of the Analytical Maintenance Program Analysis System (AMPAS)[3]. These tapes are generated from 3M data and are provided by the San Antonio Data Services Center. Two of these tapes are obtained in three sort sequences. One, the P-tape, is provided in two sort sequences. Each tape contains maintenance action records for the entire aircraft. A description of the sort sequences is provided in Volume IV of this report.

Before the algorithms can be executed, the desired WUCs must be selected, duplicate and otherwise erroneous records eliminated, and the data on the D, E, and P-tape files merged. The selected WUCs, in general, include the two-digit SWUC of the analysis and all Physically and Functionally-related WUCs external to the SWUC. The terms "Physically related WUCs (PWUCs)" and "Functionally related WUCs (FWUCs)" refer to those five-digit WUCs, internal or external to the SWUC, maintenance of which can lead to Potentially Avoidable Maintenance actions on a particular five-digit SWUC, for physical or diagnostic reasons, respectively.

Upon completion of pre-processing, the search algorithms are performed. In the following paragraphs, detailed verbal descriptions of the algorithms are provided. The bulleted criteria listed for each category may be read as a continuous descriptive sentence, one bulleted phrase following the preceding phrase.

2.1.2 No-Repairs-Required

All maintenance actions with an O-Level ATC A or an I-Level ATC A are included in this category. O and I-Level actions are

separately identified. The O&I labor rate utilized by the VAMOSC Maintenance Subsystem (MS) is used to convert labor hours to dollars[4]. In the case of an I-Level action, the O and I-Level labor times are both included.

Two additional considerations are made in the case of an I-Level action. A potentially avoidable cannibalization may be required to replace an equipment whose removal results in an I-Level No-Repairs-Required action. To identify such an event, a search is performed for:

- a cannibalization
- on the same five-digit WUC
- on another aircraft Bureau Number
- within one (1) day of the remove-and-replace action date

If a cannibalization is encountered, the labor associated with it is added to an accumulator. If the next maintenance action record in sequence is the cannibalized equipment replacement, its labor is also added to the accumulator. Generally, cannibalizations and their associated replacements occur in pairs, one JCN immediately following the other.

Whenever a remove-and-replace action occurs, it may be necessary to remove and reinstall another piece of equipment for the purpose of accessing the desired equipment. Thus, when an I-Level No-Repairs-Required action occurs, a potentially avoidable access action may be associated with it. To identify such an event, whenever an access action on an SWUC is encountered, a search is performed for:

- an I-Level No-Repairs-Required action
- on a PWUC
- initiated before the access action is initiated
- coupled with a remove-and-replace accomplished after access initiated

If such an action is encountered, the access action's labor is added to an accumulator.

2.1.3 Failure-To-Acknowledge

An occurrence of this type of PAM is identified by:

- a sequence of one or more No-Repairs-Required actions at the O Level
- no more than three (3) days apart pairwise
- on the same WUC
- on the same aircraft Bureau Number
- terminated by an O-Level corrective action

A remove-and-replace action (ATC R) is considered an O-Level corrective action as well as repair actions (ATC B or C). The time criterion for determining whether a pair of actions may be related is that one action must be initiated no more than three (3) days after the other is accomplished.

It should be noted that an occurrence of this type is not necessarily the fault of the maintenance technician or crew members. It may result from an intermittent failure, inability to reproduce a failure in the maintenance environment, or false BIT indications.

2.1.4 Failure-To-Diagnose

An occurrence of this type is identified by:

- a sequence of remove-and-replace actions
- coupled with I-Level No-Repairs-Required actions
- on SWUCs
- no more than two (2) days apart pairwise
- the latter action of each pair being functionally related to the former
- terminated by: a remove-and-replace action
  - coupled with an I-Level corrective action (ATC B or C or 1 through 9)
  - on a WUC functionally related to the last false removal

The time criterion is that one remove-and-replace action be initiated *no later than two (2) days after* the other is accomplished and no earlier than the same day the other is initiated. Since the removal date and not the replacement date is carried from the MAF through the 3M system, the I-Level action date is used as a proxy for the replacement date.

If the terminating corrective action is not found, a search is made for one which exhibits the above-described relationships to an earlier false removal in the sequence. If one is found, only the false removals occurring prior to the corrective action are added to the Failure-To-Diagnose accumulators.

It should be noted that the classification of Failure-To-Diagnose as Potentially Avoidable Maintenance does not imply that the maintenance technician is at fault. Indeed, faulty BIT may

contribute to the problem by generating false alarms. Inadequate BIT may leave ambiguity groups of WRAs in O-Level troubleshooting situations. Under the pressure of mission requirements, multiple WRA replacements may be unavoidable.

2.1.5 Failure-To-Correct

This type of PAM is identified by:

- a sequence of corrective actions
- on the same equipment part serial number
- no more than three (3) days apart pairwise

If the three-day requirement isn't met and the meter times of two consecutive actions are both available, the actions are compared according to an alternate criterion—five (5) meter hours of separation.

If the earlier corrective action of a pair takes place at the O Level, only the WUC and aircraft Bureau Number are compared with those of the latter action because the same WUC on the same aircraft Bureau Number is assumed to have the same part serial number. Redundant equipments/components have the same WUC, but different part serial numbers. However, the likelihood of two redundant units requiring corrective action within the three-day interval is considered negligible.

If the earlier corrective action of a pair occurs at the I Level, the part serial number of both actions, if available, must be identical. This comparison test is performed, where

possible, to track a piece of equipment—from I-Level maintenance, perhaps to the depot, to supply for an indefinite time, to installation on any aircraft Bureau Number. Note that if a piece of equipment is transferred to the depot and a repair is not effected, then Failure-To-Correct will be detectable only if:

- the equipment is returned to originating IMA
- another discrepancy is reported on it within the fiscal year under study
- and the equipment has an elapsed-time meter

Also note that if a piece of equipment is transferred by O-Level maintenance to the IMA, a repair not effected, and the item returned to supply for more than three days, then Failure-To-Correct will be detectable only if:

- the equipment is installed and another discrepancy reported within the fiscal year under study
- and the equipment has an elapsed-time meter

If the earlier corrective action of a pair is at the I Level, the latter action must also be at the I Level. The motivation for this criterion is as follows. If the O Level could not repair the defect identified by the earlier action, the same defect, if left uncorrected by the IMA, would again be transferred to I-Level maintenance. If, on the other hand, O-Level maintenance unsuccessfully attempts to repair a defect, subsequent attempts to repair might be deferred to the I Level.

When an occurrence of Failure-To-Correct is detected, the

costs associated with all but the chronologically last action are added to the Failure-To-Correct accumulators. The final action is interpreted to be the successful repair action. An accumulator is maintained for each of the O&I labor and material cost elements displayed in Table 2.

The O&I labor rate utilized by the VAMOSC MS is used to convert labor hours to dollars[4]. In addition, the average O&I material cost per maintenance action is computed from VAMOSC data at the four-digit WUC level.

2.1.6 Internally Induced Defect—Corrective

The detection of a defect induced in this manner may occur during a search for the type of pattern from which Failure-To-Correct is inferred. The criterion used to discriminate between these two categories of Potentially Avoidable Maintenance involves the HMC at either maintenance level. If the earlier action of a pair has an HMC not in Table 3 and the latter action has an HMC in Table 3, the inference is made that the latter action results from a defect induced during the former action. The HMCs in Table 3 are those appearing in the WUC Manual which reflect physical damage[8].

Such an induced defect, if detected, will then serve to initiate a new search for subsequent corrective actions indicating a Failure-To-Correct the induced defect. If the former action of a pair has an HMC in Table 3 and the latter does not, the former is interpreted as terminating any prior Failure-To-Correct sequence

specified therein .

5

TABLE 3. INFERRED MAINTENANCE-INDUCED DEFECT HOW-MAL CODES

CODE NO.	DESCRIPTION
070	BROKEN, BURST, RUPTURED, PUNCTURED, TORN, CUT
092	MISMATCHED-ELECTRONIC PARTS, WHEEL HALVES, ETC.
093	MISSING PART
105	LOOSE OR DAMAGED BOLTS, NUTS, SCREWS, RIVETS, FASTENERS, CLAMPS, OR OTHER COMMON HARDWARE
106	MISSING COMMON HARDWARE
108	BROKEN, FAULTY, OR MISSING SAFETY WIRE OR KEY
127	ADJUSTMENT OR ALIGNMENT IMPROPER
135	BINDING, STUCK, OR JAMMED
160	BROKEN WIRES, DEFECTIVE CONTACT OR CONNECTION
410	LACK OF, OR IMPROPER LUBRICATION
425	NICKED OR CHIPPED
585	SHEARED
651	AIR IN SYSTEM
730	LOOSE
780	BENT, BUCKLED, COLLASPED, DENTED, DISTORTED, OR TWISTED
935	SCORED, SCRATCHED, BURRED, OR GOUGED

and the latter serves to initiate a new search for subsequent corrective actions indicating a Failure-To-Correct.

As with all of the remaining categories of PAM, an accumulator is maintained for each of the cost elements in Table 2. They are estimated as follows. In addition to the O&I labor rate and material cost factors, several average maintenance costs are computed at the four-digit WUC level, from VAMOSC MS data, for estimating the costs associated with Induced Defect actions. These include:

- replenishment cost per discard
- depot labor cost per depot transfer
- depot material cost per depot transfer

The following equation was used to calculate applicable round-trip transportation costs between I-Level and depot maintenance facilities for a single item[5].

$$TC = IW \times PWR \times AD \times TR \times IF$$

where:

TC = Transportation Cost ($)

IW = Item Weight (pounds) = 25*

PWR = Packaging Weight Ratio[5] = 1.35

AD = Average Round Trip Distance (miles)[5] = 2218

TR = Transportation Rate ($/pound/mile)[5,6] = .000104 (FY 75$)

IF = Inflation Factor to FY 77$[7] = 1.163

*Assumed to be average SRA/WRA weight

Substituting in the above equation:

$$TC = 25 \times 1.35 \times 2218 \times .000104 \times 1.163$$

$$TC = \$9.05$$

This was rounded to $10.00 for use in calculation of transportation cost by computer analysis. This cost does not include associated packaging material costs or packaging labor costs.

Down-time parameters are obtained for each maintenance action from the maintenance action history files created by the pre-processing programs and utilized by the search programs as the source of all individual maintenance action data.

2.1.7 Externally Induced Defect (By PWUCs)—Corrective

An occurrence of this type of PAM is identified by:

- a sequence of corrective actions
- no more than two (2) days apart pairwise
- the former action of each pair being physically related to the latter

The first action in a sequence need not be an SWUC as the costs of all but the first action of the sequence are added to appropriate accumulators.

2.1.8 Internally Induced Defect—Non-Corrective

This type of PAM action is identified, in one of two ways, when a non-corrective action is encountered. These alternative criteria are:

- ocurrence of I-Level corrective action
- with same JCN as O-Level non-corrective action

  or

- occurrence of repair action at either level (in conjunction with O-Level remove-and-replace, if I)
- with a different JCN from that of non-corrective action
- no more than two (2) days after the non-corrective action

The costs for only the corrective action are accounted for.

2.1.9 Externally Induced Defect (By PWUCs)—Non-Corrective

This type of Potentially Avoidable Maintenance is identified by a search with the following criteria, when a non-corrective action is encountered:

- a set of one or more corrective actions
- on different SWUCs
- to each of which the WUC of the non-corrective action is physically related
- each occurring no more than two (2) days after the non-corrective action

Again, the cost of only the corrective actions are counted.

2.1.10 Reported Induced Defect

To provide a measure of the quantity of hidden Induced Defect actions (and associated cost and down time) uncovered by the PAMAS programs, accumulators are maintained for those maintenance actions for which an Induced-Defect HMC was reported. The applicable HMCs at either level of maintenance, as they appear in the WUC Manual, are[8]:

086 — IMPROPER HANDLING
246 — IMPROPER OR FAULTY MAINTENANCE
877 — TRANSPORTATION DAMAGE

2.1.11 Potential Errors of Inference

The limitation of an inferential technique, such as the one described above, is that there are two types of error, one of which inevitably increases with efforts to reduce the other. One type—which will be called inclusion error—occurs when a legitimate maintenance action, or group thereof, is determined to be potentially avoidable because it coincidentally satisfies the criteria of inference.

The other type—which will be called exclusion error—is the failure to identify true PAM actions because they do not quite satisfy the criteria. Weakening the criteria sufficiently would reduce the rate of exclusion error, but it would also increase the rate of inclusion error. This is because weakened criteria allow more legitimate and PAM actions to be identified as potentially avoidable. The opposite effect occurs when the criteria are strengthened.

In designing the algorithms and selecting time criteria, a balance was sought between inclusion and exclusion errors so that much of the PAM would be identified without including a significant number of legitimate maintenance actions.

2.1.12 Physical & Functional Relationship Identification

Two matrices were developed, by ISI hardware maintenance analysts, for each two-digit SWUC to be studied. These matrices

display, respectively, physical and functional relationships between pairs of five-digit WUCs.

The purpose of the matrices is two-fold. One benefit of the matrices is that they restrict the number of Causative WUCs (CWUCs) to be searched by the PAMAS algorithms. Secondly, they reduce the rate of inclusion error by restricting consideration to those WUC pairs which are related. This eliminates the chance of identifying, as potentially avoidable, maintenance actions among unrelated WUCs which coincidentally satisfy all of the other criteria.

The functional matrices display five-digit WUCs (WRAs) within the two-digit Subject WUC which are potentially subject to false removals at the O Level, as a result of diagnostic ambiguity, in the process of locating the failure to functionally related WRAs.

The physical matrices display five-digit WUCs (WRAs) within the two-digit Subject WUC which are potentially subject to induced defects or potentially avoidable access actions resulting from maintenance on physically related WRAs. The physically and functionally related WUCs include those which are contained in the Subject WUC and those which are not.

The rows of each matrix represent the CWUCs internal and external to the two-digit SWUC. The columns represent the five-digit SWUCs. A "1" in a cell of a matrix signifies that the CWUC of the row can induce Potentially Avoidable Maintenance on the SWUC of the intersecting column.

If any of the following criteria were satisfied, a physical

relationship was determined to exist between the pair of assemblies under consideration:

Access — SWUC needs to be removed to gain access to CWUC.

Proximity — CWUC and SWUC located closely enough that maintenance on CWUC could result in damage to SWUC.

Direct Connection — CWUC and SWUC physically attached.

The following observations about troubleshooting motivated the identification of functional relationships:

Initiation — The logic path for identifying a faulty component always begins with an observed discrepancy, e.g., "Landing Gear Position Indicator does not indicate 'WHEELS DOWN AND LOCKED.'"

Directivity — For some discrepancies, logic diagrams provide a direct path to the faulty component; sometimes the path leads to an ambiguity group.

Matrix Entries — If, for all discrepancies, the path between a pair of WUCs (say, X and Y) is directed and the direction is always the same, the matrix entries for this pair of WUCs will reflect this; if X is always tested before Y, then the matrix entry (Y,X) will be "1" and (X,Y) "0". If X and Y may be tested in either order, both entries will be "1". If there is no discrepancy for which X and Y are both tested, both entries will be "0".

The publications used to identify these physical and functional relationships were the O-Level Maintenance Instruction Manuals, for both troubleshooting and replacement, and Illustrated Parts Breakdowns[9-26]. The ISI hardware maintenance analysts who developed the matrices visited with maintenance technicians at the Norfolk, VA Naval Air Station to verify the relationships which they had identified for the F-14A (WUC 74) and the procedures utilized.

The specific physical and functional relationship matrices developed by the analysis described above are provided in Volume III of this Final Report, as well as instructions for reading these matrices.

2.1.13 Programming Considerations

Several considerations were made in the process of implementing the above-described algorithms which resulted in manageably efficient computer programs. The algorithms implemented for each category of Potentially Avoidable Maintenance perform one or two types of search.

In general, the maintenance action history files are sequentially searched for records of appropriately related actions. To minimize the time required to access all of the records of interest in a given search, there are four differently sorted maintenance action history files. Each one is used by a different set of algorithms and is created by the pre-processing programs (see Volume IV for details).

Another type of search which is performed at many points in the computer software is the table search. In particular, the SWUC, PWUC, and FWUC tables are searched, under certain circumstances, to determine whether the WUC on a particular maintenance action record belongs to a particular one of these tables and, if so, which element it is. There are several methods of performing a table search.

The simplest method is the unordered sequential search, in

which every element is tested until either the sought element is encountered or the table is exhausted. An average reduction of half of the comparison tests is achieved by ensuring that the table is in ascending order and terminating the search when either the sought element is encountered, an element of greater value is encountered, or the table is exhausted. The price of this efficiency is the need to input the table in ascending order or, alternatively, the time required to perform the sort.

The most efficient method considered is the binary search. This method also requires the tables to be in ascending order, but is much more efficient for large tables. It involves successive halving of the table until two elements remain to be tested. The break-even table size beyond which the binary search is more efficient than the ordered sequential search was estimated to be fifty (50). Since the sizes of all of the tables in this study are at least approximately equal to fifty (50), and at most much greater, the binary method was implemented in PAMAS.

An important constraint observed in programming PAMAS was to avoid multiple accounting of PAM actions and cost. One measure taken to achieve this was to account for the cost of only the O-Level portion of potentially avoidable cannibalizations and access actions because any subsequent I-Level action on the same record (derived from the same MAF) is PAM of another type, addressed by other algorithms.

Another technique employed to eliminate the possibility of multiple accounting is the maintenance of files which store keys

to the record of each PAM action of those types which are subject to multiple accounting. For example, this technique is used to prevent inferring that one cannibalization is associated with several I-Level No-Repairs-Required actions on various aircraft Bureau Numbers and counting its costs several times. Similarly, it prevents inferring that one access action is associated with several I-Level No-Repairs-Required actions on various PWUCs. In general, these key files prevent attributing a result to more than one cause.

Other programming considerations are discussed in Volume IV of this report. Flowcharts of the search algorithms described above are also provided in Volume IV.

2.2 BIT Evaluation

There are a few types of Potentially Avoidable Maintenance which are visible, though uncategorized as to cause, without sophisticated detective work. In particular, Reported Induced Defect actions are directly retrievable from the AMPAS data system. Even more readily accessed, a summary table of I-Level No-Repairs-Required actions is provided by the VAMOSC MS by four-digit WUC[4].

Among other factors, the high I-Level No-Repairs-Required Rate (NRRR) of avionics motivated the study of maintenance improvement with an effort to categorize the causes of PAM. The performance of BIT is directly related to diagnostic efficiency. Diagnostic inefficiency is partially evidenced by the rate of occurrence of No-Repairs-Required actions. Hence, the expectation

arises that the high NRRR is largely attributable to inadequate or faulty BIT.

The maintainability specification for the S-3A was reviewed in preparation for the performance evaluation of BIT on WUC 73[27]. The key qualitative observations were as follows:

- failures are to be automatically located on the ground and in flight
- failure location is to be provided to the faulty WRA without the use of special test equipment

2.2.1 BIT Error Types

Two basic parameters were computed as indicators of BIT performance—False Alarm Rate (FAR) and Failure Location Rate (FLR). BIT is an automatic inferential function, as are the PAMAS algorithms, as discussed in prior sections. As a result, it exhibits errors of inclusion and exclusion. Specifically, these errors are:

- falsely identifying a component as failed or possibly failed
- failing to detect a defect and locate suspected faulty components

The FAR and the complement of the FLR are, respectively, measures of the rates of occurrence of these two types of error. The method used for their computation will now be presented.

2.2.2 Computational Methodology

AMPAS Report No. PTX-438D[3] was used for the BIT analysis. The quantity of each type of maintenance action used to compute

these parameters excludes the suffixed actions at the I Level*. The suffixed actions reflect I-Level diagnostic effort. They do not relate to WRA location capability.

The NRRR was computed in two ways—the BIT-generated NRRR (or FAR) and the overall NRRR. The NRRR was defined as the ratio of No-Repairs-Required actions to suspected failures. The latter quantity (the denominator) was defined as the sum of failures and No-Repairs-Required actions. To determine the impact of BIT-generated No-Repairs-Required actions (false alarms), No-Repairs-Required actions were separated into those which were generated by BIT and those which were not. To this end, failures were also separated into those which were detected via BIT and those which were not.

BIT-diagnosed actions are identified by the entry, at the O Level, of one of the following HMCs. Their definitions are as they appear in the WUC Manual[8]:

290 — FAILS DIAGNOSTIC/AUTOMATIC TESTS
291 — FAILS AUTO-CHECK
293 — FAILS SELF-CHECK
294 — FAILS SELF-TEST

The FAR was defined in the same manner as the overall NRRR, except that maintenance action quantities in the numerator and denominator are replaced by their BIT-diagnosed counterparts. The complement

*The suffix is a couplet of alphanumeric characters added to the basic JCN to identify a subcomponent repair action performed independently of the major component repair[28].

of FAR, (1-FAR), is an index of the reliability of BIT indications. Two types of situation are encompassed by the parameter FAR— ambiguity among WRAs and location of the wrong WRA as the culprit. The Non-BIT-Generated NRRR (NBGNRRR) was computed in the same manner as the overall NRRR, except that only those actions not involving BIT were used.

A related parameter of interest is the False Alarm Contribution (FAC). This is defined as the ratio of false alarms to the total No-Repairs-Required actions. This parameter can be interpreted as a measure of the significance of BIT inaccuracy. Aside from unsuffixed actions, No-Repairs-Required actions result from one of several causes including:

- intermittent failure
- inability to reproduce conditions which elicited failure
- operator error
- O-Level maintenance error (Failure-To-Acknowledge)
- faulty or inadequate BIT

The FAC represents the proportional contribution of the last category to the total.

The parameter FLR is the proportion of failures detected by BIT and is defined as the ratio of BIT-detected failures to the total failures. Whereas the FAR is a measure of the rate of inclusion error, the complement of FLR, (1-FLR), is a measure of the exclusion error rate, the rate at which BIT fails to detect and locate a defect.

In conjunction with the use of HMCs to identify BIT-diagnosed actions, a question of data validity arises. In particular, the above parameter definitions assume the accurate entry of HMCs by O-Level maintenance. It is possible, however, that for a large proportion of the BIT-diagnosed actions terminating at the O Level, a HMC indicative of a specific diagnosis, rather than a BIT HMC, is entered on the MAF. This possibility is motivated by the fact that a technician who has failed to verify the existence of a defect or has repaired a defect, rather than merely replacing the WRA and transferring it to the IMA, is in a position to more explicitly describe the malfunction or its non-existence. Therefore, under the assumption that false alarms reported and BIT-detected failures repaired at the O Level are unrepresentative, the estimate of each BIT-related parameter was computed in two ways — using only I-Level data and using O and I-Level data combined.

2.3 Failure-To-Fault-Isolate

The BIT function on the S-3A provides some fault location capability below the WRA level. The following SRA isolation capability is specified for the S-3A[27]:

- In at least 90 percent of the cases of probable malfunction of an SRA, the fault shall be isolated to that sole SRA.
- In 95 percent, or more, of the cases of probable malfunction of an SRA, the fault shall be isolated to that SRA and no more than one other SRA.
- In all cases of probable malfunction of an SRA, the fault shall be isolated to that SRA and no more than two other SRAs.

In addition, the following sub-SRA isolation capability is specified for each SRA[27]:

- When the SRA contains 10 or fewer non-repairables, isolation of groups of two or less shall be possible for 50% of the possible faults. Isolation to four or less must be possible for all possible faults.
- When the SRA contains more than 10 non-repairables, isolation to groups of four or less shall be possible for 80% of the possible faults. Isolation to groups of eight or less must be possible for 95% of the possible faults. Isolation to groups of 10 or less must be possible for 100% of the possible faults.

No-Repairs-Required actions at the I Level are an indicator of the inefficiency with which fault isolation is performed at the O&I Levels. In particular, suffixed maintenance actions are those which comprise I-Level isolation to the faulty SRA(s) and, perhaps, sub-SRAs. They have the same basic JCN as the O-Level remove-and-replace charged to the parent WRA. A different suffix field is affixed to the JCN of each I-Level sub-WRA action to identify uniquely the testing or repair of each sub-component. Each suffixed action is assigned its own action date and ATC.

To quantify the efficiency of I-Level fault isolation for all of the subject aircraft, the rate of occurrence of I-Level suffixed No-Repairs-Required actions was computed for all of the Subject WUCs. This rate, denoted as the Failure-To-Fault-Isolate Rate (FTFIR), is defined as the ratio of I-Level suffixed No-Repairs-Required actions to I-Level suffixed suspected failures. The latter quantity (the denominator) is defined as the sum of suffixed I-Level failures and suffixed I-Level No-Repairs-Requied actions.

In the case of WUC 73 on the S-3A, which has an advanced BIT capability specified below the WRA level, this parameter is largely a reflection of the degree to which the BIT function is satisfying the specification. For the other aircraft (F-14A and A-7E), this parameter is an indication of the efficiency with which I-Level fault isolation is performed without the aid of BIT.

A related parameter of interest is the Failure-To-Fault-Isolate Contribution (FTFIC). This is defined as the ratio of suffixed I-Level No-Repairs-Required actions to the total I-Level No-Repairs-Required actions. This parameter can be interpreted as a measure of the significance of inefficient fault isolation at the I Level.

3.0 RESULTS

The findings of the maintenance improvement study described above are of both a quantitative and qualitative nature. They are summarized in the following paragraphs. The detailed computer printouts providing data at the five-digit WUC level are presented in Volume III.

3.1 Problems Encountered

Several observations were made during and after the process of software development and data analysis. The observation with the most significant impact on the quantitative results is that of inaccurate entry or keypunching of maintenance action dates.

Specifically, since AMPAS data tapes provide the removal date for the O-Level action date of a remove-and-replace action, it is expected that the O-Level date would always precede the I-Level date[3]. The reversal of this date order is one of several reasons for which records were eliminated by the PAMAS pre-processing programs (see Volume IV). The motivation for eliminating such records was that a record with obviously erroneous data is unreliable.

It was discovered during processing that a large proportion of rejected records were eliminated because of date reversal. Two likely explanations for this phenomenon are the failure of O-Level technicians to properly fill out a MAF or the failure of keypunchers to transcribe the removal action date to the removal card—Card Type 26[28]. If the dates are correct on the MAF,

the keypunchers may be transcribing the replacement date. On the S-3A, which is notable for its supply problem during the time frame of this study, and on the F-14A, it is possible that the IMA frequently completes corrective action before the O Level can replace the equipment, thus making the data error visible.

The impact of this problem was the reduction in detection of Potentially Avoidable Maintenance actions involving remove-and-replace or remove-and-reinstall, resulting in the elimination of an indeterminate number of sequences of related actions. The only categories unaffected are the O-Level No-Repairs-Required actions and Failure-To-Acknowledge. The category likely to be most affected is Failure-To-Daignose since only remove-and-replace actions are involved. Indeed, few (if any) instances of Failure-To-Diagnose were detected.

Another observation with some quantitative impact is that defects induced by non-corrective actions on PWUCs outside of the SWUC were inadvertently excluded. The result is quite probably minor compared to the quantity of PAM which was uncovered.

Two observations have no quantitative impact on the results of this study, but might influence future related studies. As mentioned previously, the Failure-To-Diagnose category of Potentially Avoidable Maintenance resulted in few (if any) actions. The NRRR (which includes Failure-To-Diagnose actions) was surprisingly low considering the available fleetwide data. As a result, an analysis was conducted using hard-copy AMPAS reports[3]. The results, in general, are that the NRRR of the CNAL squadrons

is much below that of the squadrons of the Commander of Naval Air Forces, Pacific (CNAP). In one case, however, that of WUC 13 on the S-3A, the CNAP data provided by AMPAS exhibited irreconcilable discrepancies with other data systems using 3M data as input. A Fiscal Year 1976 run provided similarly unreliable data for the CNAP actions on WUC 13 of the S-3A. The data summary from which these observations were drawn is provided in Table 4.

In conjunction with the above analysis, the fleetwide values of No-Repairs-Required Rate (NRRR) were estimated for each of the two-digit WUCs studied using VAMOSC MS data for Fiscal Year 1977. The No-Repairs-Required Action (NRRA) count in the VAMOSC MS is restricted to I-Level actions only. The NRRR was defined as the proportion of suspected failures resulting in No-Repairs-Required actions. For the purpose of this analysis, it was computed as the ratio of I-Level NRRAs to I-Level suspected failures, the latter quantity being the sum of I-Level failures and I-Level NRRAs. The results of this analysis are provided in Table 5.

These estimates of NRRR must be qualified. The NRRA quantity provided by the VAMOSC MS includes all such actions reported at the I Level, including those attributed to WRAs and sub-components. On the other hand, it defines I-Level failures to include such actions attributed to WRAs only, thus excluding sub-component failures. This practice inflates the estimates obtained for NRRR.

The quantity of NRRAs provided by VAMOSC MS does not include those occurring at the depot, yet the I-Level failure quantity

TABLE 4. MAINTENANCE DATA SUMMARY

DATA DESCRIPTION & SOURCE (ALL FY 1977)		TYPE/MODEL/SERIES/WORK UNIT CODE			
		F-14A	S-3A		A-7E
		WUC 74	WUC 73	WUC 13	WUC 73
(1) TOTAL UNSCHEDULED MAINTENANCE ACTIONS O&I-Levels, By Command (3M, R&M Summary)[29]	CNAL	11,633	20,134	6,223	23,899
	CNAP	12,868	17,503	7,225	26,192
	NASC	1,147	252	136	177
	TOTAL	25,588	37,889	13,584	50,268
(2) TOTAL I-LEVEL ACTION TAKEN CODE "A" (VAMOSC-MS)[4]	Unsched.	3,501	1,892	1,011	2,501
	Sched.	27	378	4	104
	I-Level TOTAL	3,528	2,270	1,015	2,605
(3) TOTAL ACTION TAKEN CODE "A", O&I-Levels (AMPAS)[3]	O-Level	2,957	5,394	817	5,708
	I-Level	3,438	2,311	245	2,588
(4) CNAL SQUADRONS ACTION TAKEN CODE "A", O&I-Levels (AMPAS)[3]	O-Level	991	2,528	304	2,734
	I-Level	1,012	838	214	695
(5) CNAL SQUADRONS ACTION TAKEN CODE "A", O&I-Levels (ISI-Screened Tapes)	O-Level	930	2,469	292	2,686
	I-Level	840	715	203	557
(6) CNAL SQUADRONS TOTAL MAINTENANCE ACTIONS O&I-Levels Combined (ISI-Screened Tapes)		12,600	20,956	5,186	25,349

NOTE: CNAL-Atlantic
CNAP-Pacific
NASC-Naval Air Systems Command

TABLE 5. FLEETWIDE NO-REPAIRS-REQUIRED RATES

T/M/S/WUC	NO-REPAIRS-REQUIRED ACTIONS (QUANTITY)	FAILURES (QUANTITY)	NO-REPAIRS-REQUIRED RATE (%)
F-14A/74	3,528	6,829	34.1
S-3A/73	2,270	7,813	22.5
S-3A/13	1,015	1,133	47.3
A-7E/73	2,605	13,692	16.0

NOTE: Based on FY 1977 VAMOSC MS data, scheduled and unscheduled combined.

includes some depot transfer actions, i.e., those with HMCs indicating failure (called unconditional). This data-processing practice results in deflation of the estimates obtained for NRRR. A partial solution of these problems would be appropriate re-definition of output data in the Maintenance Action Matrices of the VAMOSC MS.

The results of the above analysis lead, however, to the question, "Is the disparity in NRRR between the CNAL and CNAP squadrons indicative of differences in maintenance efficiency and in overall Potentially Avoidable Maintenance?"

As mentioned in Section 2.1.1, the pre-processing software was developed around three AMPAS tapes—D, E, and P. The P-tape is the only one in the series with down-time data. Its records also contain labor times. The AMPAS report generated from the P-tape displays only the maintenance actions which resulted in down time. The impression was given to ISI by AMPAS personnel that the P-tape, from which the report is generated, similarly contains only this subset of the maintenance action records. Therefore, the E-tape was utilized to provide the labor times. During processing, it was discovered that the record set on the P-tape is complete, but it was too late to streamline the software and data management process.

3.2 Quantitative Results

The numerical results of the study consist of the computed values of BIT evaluation parameters, the frequency of Failure-To-Fault-Isolate, and the output generated by PAMAS.

3.2.1 BIT Evaluation Parameters

The raw input data used to perform the computations are presented in Table 6. The symbols used in that table are defined as follows:

A_O — No-Repairs-Required actions reported at the O Level

A_I — WRA No-Repairs-Required actions reported at the I Level

F_O — WRA Failures repaired at O Level

F_I — WRA Failures repaired at I Level

FA_O — False Alarms reported at O Level

FA_I — WRA False Alarms reported at I Level

BDF_O — WRA BIT-Detected Failures repaired at O Level

BDF_I — WRA BIT-Detected Failures repaired at I Level

The results of the computations, performed as described in Section 2.2.2, are presented in Table 7. The symbols used in that table are defined as follows:

NRRR — overall No-Repairs-Required Rate (%)

NBGNRRR — Non-BIT-Generated No-Repairs-Required Rate (%)

FAR — False Alarm Rate (%)

FAC — False Alarm Contribution (%)

FLR — Failure Location Rate (%)

FAR_I — I-Level False Alarm Rate (%)

FAC_I — I-Level False Alarm Contribution (%)

FLR_I — I-Level Failure Location Rate (%)

TABLE 6. BIT EVALUATION INPUT DATA

PARAMETER	VALUE
A_O	2,528
A_I	513
F_O	2,085
F_I	3,534
FA_O	0
FA_I	59
BDF_O	41
BDF_I	909

TABLE 7. BIT PERFORMANCE PARAMETERS

	BIT-GENERATED		NRRR	
	O&I LEVELS	I-LEVEL	NON-BIT-GENERATED	OVERALL
FAR	5.8	6.1	39.0	35.1
FAC	1.9	11.5	—	—
FLR	16.9	25.7	—	—

The specifications for BIT performance parameters on the S-3A are worded in terms of design objectives, not requirements[27]. The FLR and the complement of the FAR are referred to collectively as "dependability." The dependability goals are as follows:

1-FAR = 99% (or FAR = 1%)

FLR = 98%

As compared to the desired value of FAR, the actual value, FAR_I, appearing in Table 7, is definitely higher. Based on the value of FAC_I appearing in that table, the No-Repairs-Required actions resulting from BIT equal approximately one eighth (1/8) of those resulting from other causes. The corresponding ratio of No-Repairs Required Rates equals approximately one sixth (1/6). The deviation of the actual FAR from the specified value may therefore be interpreted as being of small significance.

As compared to the objective value of FLR, the actual value, FLR_I, appearing in Table 7, is significantly lower. Therefore, while the inclusion type of BIT error occurs infrequently, the exclusion error frequency is quite high.

In general, therefore, it appears that BIT sensitivity is very low. These results are predicated on the following assumptions:

- that O-Level maintenance always enters a BIT How Malfunctioned Code (HMC) when transferring to IMA a suspected faulty WRA located by BIT
- that O-Level maintenance transfers all suspected faulty WRAs located by BIT, without double checking to verify failure
- that only faulty WRAs are transferred to the depot

- and that only assemblies truly Beyond Economical Repair are discarded

In practice, the HMC indicating the suspected cause of malfunction or code 799, indicating No Defect, may frequently be entered on the MAF. Suspected faulty WRAs located by BIT may be screened for verification, thus reducing the No-Repairs-Required action count at the I Level. It is quite possible that a significant proportion of the WRAs transferred to depot maintenance are determined at the depot to be non-defective.

The impact of the assumptions about maintenance and reporting practices on the results of the BIT analysis could be significant. The accuracy of the results, therefore, cannot be fully verified without conducting a field investigation.

3.2.2 Failure-To-Fault-Isolate Computation

The raw input data used to perform the computations are presented in Table 8. The results of the computations, performed as described in Section 2.3, are presented in Table 9.

Although the F-14A and the S-3A avionics are more modern and incorporate more extensive BIT than that of the A-7E, the resulting values of FTFIR and FTFIC (Table 9) appear to indicate that the inefficiency of fault isolation at the I Level is significantly greater for more modern aircraft. This may reflect the greater complexity of their avionics. Another possible explanation for this anomaly is as follows. The A-7E was first introduced to operational status in 1969, whereas the S-3A and the F-14A were

TABLE 8. FAILURE-TO-FAULT-ISOLATE INPUT DATA

T/M/S/WUC	SA	SF	A_I
F-14A/74	322	1,613	1,012
S-3A/73	325	2,414	838
S-3A/13	0	105	214
A-7E/73	73	3,573	695

TABLE 9. FAILURE-TO-FAULT-ISOLATE PARAMETERS

T/M/S/WUC	FTFIR %	FTFIC %
F-14A/74	16.6	31.8
S-3A/73	11.9	38.8
S-3A/13	0	0
A-7E/73	2.0	10.5

SA — Suffixed I-Level No-Repairs-Required Actions
SF — Suffixed Failures processed at the I Level
A_I — total I-Level No-Repairs-Required Actions

FTFIR — Failure-To-Fault-Isolate Rate
FTFIC — Failure-To-Fault-Isolate Contribution

introduced in 1973 and 1972, respectively. There has also been a larger quantity of A-7Es in operation than the other aircraft. Since its introduction, the maintainability of the A-7E and the capability of its maintenance organization may have improved through the processes of design modification and maintenance experience. An alternative explanation for the discrepancy noted above is as follows. The F-14A and the S-3A rely heavily on BIT and automatic shop test equipment (VAST) for SRA fault isolation, while the A-7E has depended mainly on bench test by more conventional means. On the modern aircraft, BIT/VAST identifies a faulty SRA, whihc is further checked and repaired, if necessary, possibly by different personnel. In the case of the A-7E, the faulty SRA is identified and repaired, if necessary, by the same personnel, who may be reluctant to report a No-Repairs-Required action if a suspect SRA does not prove to be faulty.

In the case of non-avionic equipment, such as landing gear (S-3A/13), no such diagnostic inefficiency is revealed by this analysis. This most likely reflects the more readily visually detectable failures among mechanical components.

3.2.3 Potentially Avoidable Maintenance Assessment System (PAMAS) Output

For each five-digit SWUC, of each subject aircraft T/M/S of this study, detailed computer input and output tables are provided in Volume III of this Final Report. Four-digit SWUCs were included by treating them as five-digit WUCs with a "0" as the fifth digit. Each output table of Volume III provides, for a specific PAM action

category, the value of all applicable cost/down-time elements estimated via the PAMAS algorithms. The above categories and elements are as identified previously, in Tables 1 and 2 of this Volume, respectively. In addition, these provide the quantity of maintenance actions in each category, and the O&I Level Maintenance Man-Hours (MMH) associated with these actions. The down-time elements displayed in these tables (i.e., NORMU, NORS and AWM) are as defined in the Aircraft Inventory Reporting System (OPNAVINST 5442.2D) and the Naval Aviation Maintenance Program (OPNAVINST 4790.2A)[30,28]. It should be noted that AWM time considered in this study is only that which is associated with NORMU time. NORMU(P) time, as indicated in the cost element structure (Table 2), represents that portion of NORMU time which is associated with active maintenance. It should be noted that the term "NORMU" as used here refers to all NORM time associated with PAM actions.

Tables 10 through 13 summarize, at the two-digit SWUC level, the detailed computer-generated results from Volume III, for each T/M/S/SWUC combination. The maintenance action categories and cost/down-time elements are the same as previously defined. The column in these tables headed "Vol. III Table No." serves as a cross reference. The table number adjacent to each category identifies the corresponding computer output table appearing in Volume III. It should be noted that there are two categories (Failure-To-Acknowledge and Failure-To-Diagnose) which are shown separately to quantify their contribution to the respective No-

TABLE 10. F-14A (WUC 74), MAINTENANCE IMPROVEMENT POTENTIAL (CNAL SQUADRONS ONLY)

MAINTENANCE ACTION CATEGORIES	VOL. III TABLE NO.	ACTIONS (QTY)	MMH TIME (HRS)	O&I LEVEL LABOR COST ($)	O&I LEVEL MATERIAL COST ($)	I-LEVEL DISCARD ($)	DEPOT LABOR ($)	DEPOT MAT. ($)	DEPOT TRANS. ($)	NORMU TIME (HRS)	NORS TIME (HRS)	AWM TIME (HRS)
O-LEVEL NO REPAIRS REQUIRED	8	930	2,772.0	38,669.30						1,740.8	191.9	1,069.3
I-LEVEL NO REPAIRS REQUIRED	9	840	4,681.8	65,311.03						802.6	442.5	340.3
ACCESS ACTIONS	10	18	47.0	655.65						0.0	0.0	0.0
CANNIBALIZATIONS	11	375	1,390.1	19,391.85						0.0	0.0	0.0
FAILURE TO ACKNOWLEDGE (1)	12	86	313.2	4,369.13						158.2	0.0	14.6
FAILURE TO DIAGNOSE (2)	13											
NO REPAIRS REQUIRED	13	10	89.6	1,249.91						3.8	0.0	0.0
ACCESS ACTIONS	13	0										
FAILURE TO CORRECT	14	76	1,340.0	18,699.94	3,315.14					58.2	45.0	19.0
DEFECTS INDUCED INTERNALLY BY CORR. ACT.	15	18	303.6	4,235.21	808.99	0.00	657.22	234.92	10.00	50.3	0.0	0.0
REPORTED INDUCED DEFECTS	16	9	96.0	1,339.18	496.19	0.00	1,118.76	465.69	20.00	10.0	0.0	1.7
DEFECTS INDUCED ON PHYSICALLY RELATED ITEMS BY CORR. ACT.	17	123	1,577.2	22,001.88	6,346.81	0.00	3,028.88	1,139.68	50.00	51.6	17.0	2.1
DEFECTS INDUCED INTERNALLY BY NON-CORR. ACT.	18	102	1,519.0	21,189.99	4,623.62	0.00	5,573.10	1,888.19	100.00	20.8	149.0	8.0
DEFECTS INDUCED ON PHYSICALLY RELATED ITEMS BY NON-CORR. ACT.	19	38	359.6	5,016.42	2,197.33	3,800.00	194.44	638.89	10.00	0.0	0.0	0.0
SUB-TOTALS		2,529	14,086.8	196,510.45	17,788.08	3,800.00	10,572.40	4,367.37	190.00	2,734.3	845.4	1,440.4
COST TOTAL ($)				← 233,228.30 →								

(1) Included in O-LEVEL NO REPAIRS REQUIRED

(2) Included in I-LEVEL NO REPAIRS REQUIRED

TABLE 11. S-3A (WUC 73), MAINTENANCE IMPROVEMENT POTENTIAL (CNAL SQUADRONS ONLY)

MAINTENANCE ACTION CATEGORIES	VOL. III TABLE NO.	ACTIONS (QTY)	MMH TIME (HRS)	O&I LEVEL LABOR COST ($)	O&I LEVEL MATERIAL COST ($)	I-LEVEL DISCARD ($)	DEPOT LABOR ($)	DEPOT MAT. ($)	DEPOT TRANS. ($)	NORMU TIME (HRS)	NORS TIME (HRS)	AWM TIME (HRS)
O-LEVEL NO REPAIRS REQUIRED	44	2,469	6,058.9	84,521.48						1,080.8	12.0	644.4
I-LEVEL NO REPAIRS REQUIRED	45	715	3,929.7	54,819.21						532.7	1,171.8	344.6
ACCESS ACTIONS	46	0										
CANNIBALIZATIONS	47	298	744.7	10,388.48						0.8	0.0	0.0
FAILURE TO ACKNOWLEDGE (1)	48	172	433.2	6,043.10						94.3	0.0	17.0
FAILURE TO DIAGNOSE (2)	49											
NO REPAIRS REQUIRED	49	0										
ACCESS ACTIONS	49	0										
FAILURE TO CORRECT	50	138	1,718.0	23,966.07	4,653.59					49.6	10.0	0.0
DEFECTS INDUCED INTERNALLY BY CORR. ACT.	51	13	73.2	1,021.12	425.62	0.00	559.39	61.30	10.00	4.0	0.0	0.0
REPORTED INDUCED DEFECTS	52	20	106.6	1,487.05	719.37	0.00	5,956.36	652.73	10.00	0.0	0.0	0.0
DEFECTS INDUCED ON PHYSICALLY RELATED ITEMS BY CORR. ACT.	53	168	2,493.9	34,789.86	5,291.94	0.00	52,880.68	5,795.21	180.00	90.1	1,164.5	54.0
DEFECTS INDUCED INTERNALLY BY NON-CORR. ACT.	54	308	4,345.5	60,619.65	9,227.32	0.00	136.589.52	15,032.33	700.00	562.5	1,285.3	524.5
DEFECTS INDUCED ON PHYSICALLY RELATED ITEMS BY NON-CORR. ACT.	55	0										
SUB-TOTALS		4,129	19,470.5	271,612.92	20,344.84	0.00	195,985.95	21,541.57	900.00	2,320.5	3,643.6	1,567.5
COST TOTAL ($)				← 510,385.28 →								

(1) Included in O-LEVEL NO REPAIRS REQUIRED

(2) Included in I-LEVEL NO REPAIRS REQUIRED

TABLE 12. S-3A (WUC 13), MAINTENANCE IMPROVEMENT POTENTIAL (CNAL SQUADRONS ONLY)

MAINTENANCE ACTION CATEGORIES	VOL. III TABLE NO.	ACTIONS (QTY)	MMH TIME (HRS)	O&I LEVEL LABOR COST ($)	O&I LEVEL MATERIAL COST ($)	I-LEVEL DISCARD ($)	DEPOT LABOR ($)	DEPOT MAT. ($)	DEPOT TRANS. ($)	NORMU TIME (HRS)	NORS TIME (HRS)	AWM TIME (HRS)
O-LEVEL NO REPAIRS REQUIRED	26	292	1,319.4	18,405.51						765.3	52.5	393.1
I-LEVEL NO REPAIRS REQUIRED	27	203	1,315.3	18,348.43						169.9	119.8	68.9
ACCESS ACTIONS	28	0										
CANNIBALIZATIONS	29	8	20.5	285.97						0.0	0.0	0.0
FAILURE TO ACKNOWLEDGE (1)	30	14	38.9	542.64						12.2	52.5	2.0
FAILURE TO DIAGNOSE (2)	31											
NO REPAIRS REQUIRED	31	0										
ACCESS ACTIONS	31	0										
FAILURE TO CORRECT	32	63	356.2	4,968.96	4,172.80					137.3	0.0	40.0
DEFECTS INDUCED INTERNALLY BY CORR. ACT.	33	9	73.3	1,022.53	707.81	0.00	454.55	90.91	10.00	25.3	24.0	0.0
REPORTED INDUCED DEFECTS	34	37	70.5	983.45	1,220.66	0.00	0.00	0.00	0.00	0.0	0.0	0.0
DEFECTS INDUCED ON PHYSICALLY RELATED ITEMS BY CORR. ACT.	35	25	63.4	884.41	1,824.92	0.00	6,551.83	1,672.18	70.00	14.0	0.0	0.0
DEFECTS INDUCED INTERNALLY BY NON-CORR. ACT.	36	59	206.7	2,883.44	1,499.57	3,795.00	30,788.09	7,456.83	140.00	11.0	586.5	7.5
DEFECTS INDUCED ON PHYSICALLY RELATED ITEMS BY NON-CORR. ACT.	37	0										
SUB-TOTALS		696	3,425.3	47,782.70	9,425.76	3,795.00	37,794.47	9,219.92	220.00	1,122.8	782.8	509.5
COST TOTAL ($)				108,237.85								

(1) Included in O-LEVEL NO REPAIRS REQUIRED

(2) Included in I-LEVEL NO REPAIRS REQUIRED

TABLE 13. A-7E (WUC 73), MAINTENANCE IMPROVEMENT POTENTIAL (CNAL SQUADRONS ONLY)

MAINTENANCE ACTION CATEGORIES	VOL. III TABLE NO.	ACTIONS (QTY)	MMH TIME (HRS)	O&I LEVEL LABOR COST ($)	O&I LEVEL MATERIAL COST ($)	I-LEVEL DISCARD ($)	DEPOT LABOR ($)	DEPOT MAT. ($)	DEPOT TRANS. ($)	NORMU TIME (HRS)	NORS TIME (HRS)	AWM TIME (HRS)
O-LEVEL NO REPAIRS REQUIRED	62	2,686	6,629.4	92,480.08						728.3	16.2	316.8
I-LEVEL NO REPAIRS REQUIRED	63	557	6,719.5	93,736.98						186.2	254.4	105.5
ACCESS ACTIONS	64	0										
CANNIBALIZATIONS	65	350	1,261.1	17,592.31						3.3	44.1	0.0
FAILURE TO ACKNOWLEDGE (1)	66	208	507.4	7,078.21						56.3	0.0	8.1
FAILURE TO DIAGNOSE (2)	67											
NO REPAIRS REQUIRED	67	4	34.7	484.06						0.0	0.0	0.0
ACCESS ACTIONS	67	0										
FAILURE TO CORRECT	68	405	3,369.3	47,001.68	38,496.27					187.2	131.8	76.8
DEFECTS INDUCED INTERNALLY BY CORR. ACT.	69	89	852.4	11,890.95	8,868.22	0.00	2,191.16	311.05	20.00	17.2	267.9	0.0
REPORTED INDUCED DEFECTS	N/A	N/A										
DEFECTS INDUCED ON PHYSICALLY RELATED ITEMS BY CORR. ACT.	N/A	N/A										
DEFECTS INDUCED INTERNALLY BY NON-CORR. ACT.	N/A	N/A										
DEFECTS INDUCED ON PHYSICALLY RELATED ITEMS BY NON-CORR. ACT.	N/A	N/A										
SUB-TOTALS		4,087	18,831.7	262,702.00	47,364.49	0.00	2,191.16	311.05	20.00	1,122.2	714.4	499.1
COST TOTAL ($)				←		312,588.70			→			

(1) Included in O-LEVEL NO REPAIRS REQUIRED

(2) Included in I-LEVEL NO REPAIRS REQUIRED

Repairs-Required categories, but not included in the totals. To add them would be double accounting.

For ease of discussion, the values in Tables 10 through 13 are further summarized in Table 14 through 17, respectively. In contrast to the more detailed matrices (Tables 10 to 13), the cost of potentially avoidable access actions and cannibalizations are included in the cost values for I-Level No-Repairs-Required. These are included under this category as they directly relate to I-Level No-Repairs-Required actions even though performed by O-Level maintenance personnel. These two categories are reported actions, but they are not reported as Potentially Avoidable Maintenance actions. Therefore, for visibility, the No-Repairs-Required and Induced Defect categories are aggregated in sub-totals as shown in Tables 14 through 17.

It should be noted that in Tables 13 and 17, for the A-7E (WUC 73), only one category of Induced Defect is shown. The N/As in these tables indicate the categories not analyzed.

3.2.3.1 Extent of Potentially Avoidable Maintenance Uncovered

To highlight the degree to which the PAMAS algorithms uncovered PAM actions not reported as such, the quantity of actions, cost, and NOR time associated with reported and inferred types of Potentially Avoidable Maintenance are presented in summary form in Table 18. The Reported categories (as listed in Tables 10 through 13) are the following:

- O-Level No-Repairs-Required

TABLE 14. POTENTIALLY AVOIDABLE MAINTENANCE SUMMARY - F-14A (WUC 74)

CATEGORY	ACTIONS (QTY)	BELOW DEPOT LABOR & MATERIAL COST ($)	DEPOT LABOR, MATERIAL, & TRANSPORTATION COST ($)	TOTAL COST ($)	NOR TIME (HOURS)
NO REPAIRS REQUIRED					
O-LEVEL					
REPORTED	930	38,669.30		38,669.30	1,932.7
I-LEVEL					
REPORTED	840	85,358.53		85,358.53	1,245.1
INFERRED	393				
SUB-TOTAL	2,163	124,027.83		124,027.83	3,177.8
FAILURE TO CORRECT					
INFEREED	76	22,015.08		22,015.08	103.2
INDUCED DEFECT					
REPORTED	9	1,835.37	1,604.45	3,439.82	10.0
INFERRED	281	70,220.25	13,525.32	83,745.57	288.7
SUB-TOTAL	290	72,129.77	15,129.77	87,185.39	298.7
TOTAL	2,529	218,098.53	15,129.77	233,228.30	3,579.7

TABLE 15. POTENTIALLY AVOIDABLE MAINTENANCE SUMMARY - S-3A (WUC 73)

CATEGORY	ACTIONS (QTY)	BELOW DEPOT LABOR & MATERIAL COST ($)	DEPOT LABOR, MATERIAL, & TRANSPORTATION COST ($)	TOTAL COST ($)	NOR TIME (HOURS)
NO REPAIRS REQUIRED					
O-LEVEL					
REPORTED	2,469	84,521.48		84,521.48	1,092.8
I-LEVEL					
REPORTED	715	65,207.69		65,207.69	1,705.3
INFERRED	298				
SUB-TOTAL	3,482	149,729.17		149,729.17	2,798.1
FAILURE TO CORRECT					
INFERRED	138	28,619.66		28,619.66	59.6
INDUCED DEFECT					
REPORTED	20	2,206.42	6,619.09	8,825.51	0
INFERRED	489	111,402.51	211,808.43	323,210.94	3,106.4
SUB-TOTAL	509	113,608.93	218,427.52	332,036.45	3,106.4
TOTAL	4,129	291,957.76	218,427.52	510,385.28	5,964.1

TABLE 16. POTENTIALLY AVOIDABLE MAINTENANCE SUMMARY - S-3A (WUC 13)

CATEGORY	ACTIONS (QTY)	BELOW DEPOT LABOR & MATERIAL COST ($)	DEPOT LABOR, MATERIAL, & TRANSPORTATION COST ($)	TOTAL COST ($)	NOR TIME (HOURS)
NO REPAIRS REQUIRED					
O-LEVEL					
REPORTED	292	18,405.51		18,405.51	817.8
I-LEVEL					
REPORTED	203	18,634.40		18,634.40	289.7
INFERRED	8				
SUB-TOTAL	503	37,039.91		37,039.91	1,107.5
FAILURE TO CORRECT					
INFERRED	63	9,141.76		9,141.76	137.3
INDUCED DEFECT					
REPORTED	37	2,204.11	0	2,204.11	0
INFERRED	93	12,617.68	47,234.39	59,582.07	660.8
SUB-TOTAL	130	14,821.79	47,234.39	62,056.18	660.8
TOTAL	696	61,003.46	47,234.39	108,237.85	1,905.6

TABLE 17. POTENTIALLY AVOIDABLE MAINTENANCE SUMMARY - A-7E (WUC 73)*

CATEGORY	ACTIONS (QTY)	BELOW DEPOT LABOR & MATERIAL COST ($)	DEPOT LABOR, MATERIAL, & TRANSPORTATION COST ($)	TOTAL COST ($)	NOR TIME (HOURS)
NO REPAIRS REQUIRED					
O-LEVEL					
REPORTED	2,686	92,480.08		92,480.08	744.5
I-LEVEL					
REPORTED	557	111,329.29		111,329.29	488
INFERRED	350				
SUB-TOTAL	3,593	203,809.37		203,809.37	1,232.5
FAILURE TO CORRECT					
INFERRED	405	85,497.95		85,497.95	319
INDUCED DEFECT*					
REPORTED	N/A	N/A	N/A	N/A	N/A
INFERRED	89	20,759.17	2,522.21	23,281.38	285.1
SUB-TOTAL	89	20,759.17	2,522.21	23,281.38	285.1
TOTAL*	4,087	310,066.49	2,522.21	312,588.70	1,836.6

* Reflects values of partial INDUCED DEFECT analysis.

- I-Level No-Repairs-Required
- Reported Induced Defect

The remaining categories are denoted as Inferred.

In addition to the value of this inferred maintenance impact (which is only that uncovered by these analyses but certainly not all), its relative impact is also provided. This is expressed as a percentage of the total PAM impact of reported and inferred actions.

The A-7E (WUC 73) was excluded from Table 18, as the Induced Defect analysis was only partially performed for this WUC. The PAM impact in Table 18 is a conservative estimate. Were it not for the maintenance action date-reversal problem and the non-corrective action induced defect problem described in Section 3.1, the impact shown in Table 18 would be greater. As an example, the quantity of I-Level No-Repairs-Required actions omitted as a result of the date-reversal problem is indicated by comparing Items 4 and 5 in Table 4 for each T/M/S/SWUC.

It should be further noted that possible PAM problems at the depot level were not considered in this study.

3.2.3.2 Analysis of Impact of Specific Five-Digit WUCs

An analysis of the computer output generated by this study was conducted at the five-digit WUC level within a selected four-digit WUC. First, as an example, the four-digit WUC with the greatest contribution to total maintenance cost was identified

TABLE 18. EXTENT OF POTENTIALLY AVOIDABLE MAINTENANCE UNCOVERED

T/M/S/WUC	ACTION (QUANTITY)			COST ($)		NOR TIME (HOURS)	
F-14A/74	REPORTED	1,779		107,402.15		3,187.8	
	INFERRED	750		125,808.15		391.9	
	% OF TOTAL		30		54		11
S-3A/73	REPORTED	3,204		148,166.20		2,797.3	
	INFERRED	925		362,219.08		3,166.8	
	% OF TOTAL		22		71		53
S-3A/13	REPORTED	532		38,958.05		1,107.5	
	INFERRED	164		69,279.80		798.1	
	% OF TOTAL		24		64		42
TOTAL	REPORTED	5,515		294,544.40		7,092.6	
	INFERRED	1,839		557,307.03		4,356.8	
	% OF TOTAL		25		65		38

within the F-14A Fire Control (WUC 74), based on FY 1977 VAMOSC MS data, as depicted in Table 19. It should be noted that the F-14A Fire Control comprises 15 four-digit WUCs.

TABLE 19. 4-DIGIT WUC SELECTION

2-DIGIT TOTAL MAINTENANCE COST	$6,884K
HIGHEST 4-DIGIT CONTRIBUTOR	WUC 74A1
4-DIGIT TOTAL MAINTENANCE COST	$3,631K
4-DIGIT % OF 2-DIGIT MAINTENANCE COST	52.7%

Then, for each PAM category, based on PAM data for CNAL squadrons in FY 1977, the top two five-digit WUC contributors to the cost, NOR time, and NORM time associated with that category were identified within that previously selected four-digit WUC. It should be noted that WUC 74A1 comprises 32 five-digit WUCs. The results of this analysis are presented in Table 20. These results demonstrate the usefulness of the technique developed for this study in pinpointing problem areas for further study and improvement.

In particular, implementation of this technique might lead to the identification and mitigation of specific causes of problems on existing weapon systems, as well as the development of

TABLE 20. HIGHEST 5-DIGIT COST & DOWN-TIME CONTRIBUTORS (F-14A FIRE CONTROL, WUC 74A1)

		POTENTIALLY AVOIDABLE MAINTENANCE CATEGORY							
		NO REPAIRS REQUIRED		FAILURE TO CORRECT		INDUCED DEFECTS		OVERALL	
4-DIG. PAM COST	($)	69,523		8,147		45,500		123,170	
TWO HIGHEST 5-DIG. CONTRIBUTORS	(WUC)	74A10	74A15	74A1G	74A15	74A1G	74A11	74A10	74A1G
5-DIG. PAM COST	($)	21,870	10,773	2,037	789	8,500	7,846	24,645	19,264
5-DIG. % OF 4-DIG. PAM COST	(%)	31.5	15.5	25.0	9.7	18.7	17.2	20.0	15.6
4-DIG. PAM NOR TIME	(HRS)	2,777.8		76.8		93.6		2,948.2	
TWO HIGHEST 5-DIG. CONTRIBUTORS	(WUC)	74A10	74A15	74A1X	74A1G	74A15	74A11	74A10	74A15
5-DIG. PAM NOR TIME	(HRS)	1,691.8	461.6	45.0	28.6	31.0	23.8	1,715.6	492.6
5-DIG. % OF 4-DIG. PAM NOR	(%)	60.9	16.6	58.6	37.2	33.1	25.4	58.2	16.7
4-DIG. PAM NORM TIME	(HRS)	2,343.7		31.8		75.1		2,450.6	
TWO HIGHEST 5-DIG. CONTRIBUTORS	(WUC)	74A10	74A15	74A1G	74A18	74A15	74A11	74A10	74A15
5-DIG. PAM NORM TIME	(HRS)	1,512.8	409.6	28.6	2.2	31.0	15.3	1,525.6	440.6
5-DIG. % OF 4-DIG. PAM NORM	(%)	64.5	17.5	90.0	6.9	41.3	20.4	62.3	18.0

Note: Based on PAM identified by this study (CNAL squadrons only).

guidelines, policies, and/or models which could be applied in the planning and design stages of new weapon systems to the prevention of some of their Potentially Avoidable Maintenance.

It should be noted that actions attributed to four-digit WUCs were considered in this study by denoting four-digit WUCs as five-digit WUCs with "0" in the fifth position. Because many No-Repairs-Required actions are reported against the four-digit WUC at the O Level, the five-digit WUC 74A10 was found to be the biggest single contributor to overall PAM cost, NOR time, and NORM time for the four-digit WUC 74A1. No-Repairs-Required actions appear to have contributed the overwhelming portion of NOR and NORM times to the total potentially avoidable NOR and NORM times and a majority of the total potentially avoidable cost.

3.2.3.3 Significance of Results

The following comparisons and observations are based on the results obtained for all the T/M/S/SWUCs except the A-7E/73, the results for which are limited as described previously.

Each category of Potentially Avoidable Maintenance is associated with its own set of cost elements. Induced Defect affects all the cost elements under consideration. No-Repairs-Required, on the other hand, affects only O and I-Level labor costs, whereas Failure-To-Correct affects both labor and material costs at these levels.

Induced Defect and No-Repairs-Required are the greatest contributors to Potentially Avoidable Maintenance costs and NOR time

for the SWUCs studied. Failure-To-Correct contributed a relatively small percentage of the cost and NOR time. This is clearly shown in Tables 14 through 16.

As can be seen in Tables 10 through 12, O&I Level Labor is the largest single contributor to PAM cost. For avionic WUCs, potentially avoidable cannibalizations represent a significant additional cost with regard to the resultant I-Level No-Repairs-Required cost. For the S-3A (WUCs 13 and 73), depot labor is by far the second largest contributor. In the case of the F-14A (WUC 74), O&I Level Material costs are the second largest contributor. The reason for this difference appears to be the relatively small number of depot transfers on the F-14A (WUC 74)—19 transfer actions out of 290 Induced Defect actions, or 6.6%. For the S-3A (WUC 73), there were 90 transfer actions out of 509 Induced Defect actions, or 17.7%; and for the S-3A (WUC 13) there were 22 transfer actions out of 126 Induced Defect actions, or 17.5%.

This observation may be related to the degree to which I-Level maintenance is authorized to do repairs. It should be noted that, in the case of the S-3A (WUC 73), no I-Level Discard cost was incurred, as compared to $3,800.00 for the F-14 (WUC 74). The lower cost of this element for the S-3A (WUC 73) partially compensates for the higher cost of depot maintenance.

Potentially avoidable cannibalizations—i.e., those necessitated by false removals on another aircraft—of avionic WRAs were found to occur rather frequently, relative to the quantity of

I-Level No-Repairs-Required actions. Although the S-3A is known to have experienced a supply problem during the sample time interval, the occurrence of potentially avoidable cannibalizations was found to be more significant on the subject WUCs of the F-14A and A-7E. This suggests that while the S-3A avionics suffered a high cannibalization rate, most of the cannibalizations were associated with failures, not false removals.

Potentially avoidable access actions were, in general, found to be of insignificant impact. Thus, while physical proximity of equipments results in a significant incidence of induced defects, access difficulties do not seem to significantly contribute to Potentially Avoidable Maintenance. An explanation is that suspected failures may be verified at the O Level if a remove-and-reinstall action would be required to facilitate a removal. Another explanation is that access actions may frequently go unreported.

The quantity of Failure-To-Acknowledge actions was found in all cases to account for less than 10% of the O-Level No-Repairs-Required actions. This suggests that other causes of these PAM actions are more significant. In particular, these causes may include intermittent failures, failures which can't be duplicated in a maintenance environment, false Built-In Test (BIT) indications, and unverified complaints of operations personnel.

3.2.3.4 Projection of Results

The results described in the previous sections apply only to the specific WUCs analyzed and to CNAL squadrons. It would

be ideal to perform similar analyses for the same SWUCs in the CNAP squadrons to obtain Fleetwide cost impact, but this was beyond the scope of the current study. However, projections of these results were made in order to appreciate their significance. Based on analyses of the CNAL squadrons, in conjunction with related Fleetwide and CNAP maintenance action data (from Table 4), a rough cost projection was made to the Fleetwide level for the SWUCs. The projection methodology and results are described below in the following order:

1. upward scaling of A-7E cost to account for the partial analysis performed
2. cost projection for each SWUC from CNAL to Fleet
3. upward scaling of A-7E NOR to account for the partial analysis performed

3.2.3.4.1 <u>A-7E (WUC 73) Cost Projection</u>

Before the cost projection could be performed for the A-7E, it was necessary to scale upward its estimated PAM impact to account for the fact that the Induced Defect analysis was only partially performed. This was accomplished as follows. Using Tables 10 and 11, a weighted average proportion (for the F-14A and S-3A avionics) of PAM cost associated with the Induced Defect program was computed. This included the following maintenance action categories listed in Tables 10 and 11:

- Reported Induced Defects
- Defects Induced by Corr. Act. on Physically Related Items
- Defects Induced Internally by Non-Corr. Act.

- Defects Induced by Non-Corr. Act. on Physically Related Items

The result was that, on the average, 55% of the total PAM cost was disclosed by this portion of the Induced Defect analysis. The PAM cost disclosed by the programs executed for the A-7E was scaled according to this proportion to yield an estimate of the total cost. This calculation was accomplished as follows:

$$\text{ESTIMATED PAM COST}_{(\text{A-7E/WUC 73})} = \frac{\$312{,}588.70}{.45} \text{ (From Table 13)}$$

$$= \$694{,}642.$$

This value, as well as those for the other T/M/S/SWUCs (taken from Tables 10 to 12), are shown in Table 21 (Column 1).

3.2.3.4.2 <u>Fleetwide SWUC Cost Projections</u>

The cost projection to the Fleet level, shown in Table 21, was accomplished for each SWUC as follows. The PAM Cost (PAMC) for CNAL squadrons (Column 1), was separated into the cost associated with No-Repairs-Required Actions (NRRA, Column 2) and the remaining Other PAM Cost (Other PAMC, Column 3). These two costs were scaled separately: the former by the ratio of Fleet NRRAs (Column 4) to CNAL NRRAs (as identified by ISI, Column 5); the latter by the ratio of Fleetwide Unscheduled Maintenance Actions (UMA, Column 7) less Fleetwide NRRAs (Column 4) to the CNAL UMAs (Column 8) less the CNAL NRRAs (Column 6). This projection is expressed symbolically as follows:

TABLE 21. POTENTIALLY AVOIDABLE MAINTENANCE COST PROJECTION TO FLEET LEVEL FOR EACH SWUC

T/M/S/SWUC	1 PAMC, CNAL ($)	2 NRRA, ISI ($)	3 OTHER PAMC ($)	4 FLEET NRRA (QTY) AMPAS	5 CNAL NRRA (QTY) ISI	6 CNAL NRRA (QTY) AMPAS	7 FLEET UMA (QTY)	8 CNAL UMA (QTY)	9 PAMC, FLEET SWUCs ($)
F-14A/74	233,328.30	124,027.83	109,300.47	O- 2,957 I- 3,438 TOT. 6,395	O- 930 I- 840 TOT. 1,770	O- 991 I- 1,012 TOT. 2,003	25,588	11,633	665,952.
S-3A/73	510,385.28	149,729.17	360,656.11	O- 5,394 I- 2,311 TOT. 7,705	O- 2,469 I- 715 TOT. 3,184	O- 2,528 I- 838 TOT. 3,366	37,889	20,134	1,011,546.
S-3A/13	108,237.85	37,039.91	71,197.94	O- 817 I- 1,015 TOT. 1,832	O- 292 I- 203 TOT. 495	O- 304 I- 214 TOT. 518	13,584	6,223	283,749.
A-7E/73 *	694,641.56	203,809.37	490,832.19	O- 5,708 I- 2,588 TOT. 8,296	O- 2,686 I- 557 TOT. 3,243	O- 2,734 I- 695 TOT. 3,429	50,268	23,899	1,527,780.

TOTAL (FY 77 $)	3,489,027.
TOTAL (FY 79 $)	x 1.14 3,977,491

1 From Tables 10. (F-14A/74), 11. (S-3A/73), 12. (S-3A/13), Para. 3.2.3.4.1 (A-7E/73)
2 From Tables 14. (F-14A/74), 15. (S-3A/73), 16. (S-3A/13), 17. (A-7E/73)
3 Columns 1 - 2
4 From Table 4. Item (3), except I-Level S-3A/13 Table 4. Item (2)
5 From Table 4. Item (5)
6 From Table 4. Item (4)
7 From Table 4. Item (1)
8 From Table 4. Item (1)

* Partial projection

$$PAMC_{FLEET} = \$(NRRA,\ ISI) \times \frac{QTY\ (NRRA,\ FLEET,\ AMPAS)}{QTY\ (NRRA,\ CNAL,\ ISI)}$$

$$+ \$(OTHER\ PAMC,\ ISI) \times \frac{QTY\ (UMA,\ FLEET) - QTY\ (NRRA,\ FLEET)}{QTY\ (UMA,\ CNAL) - QTY\ (NRRA,\ CNAL,\ AMPAS)}$$

(column numbers: $PAMC_{FLEET}$ ⑨; $(NRRA, ISI)$ ②; QTY (NRRA, FLEET, AMPAS) ④; QTY (NRRA, CNAL, ISI) ⑤; $(OTHER PAMC, ISI)$ ③; QTY (UMA, FLEET) ⑦; QTY (NRRA, FLEET) ④; QTY (UMA, CNAL) ⑧; QTY (NRRA, CNAL, AMPAS) ⑥)

(NOTE: (No.) = TABLE 21 COLUMN NUMBERS)

It should be noted that the term "UMA" denotes all actions initiated by unscheduled maintenance, including those identified as potentially avoidable. The results of the above computation shown in Table 21 is a rough estimate of the Potentially Avoidable Maintenance Cost for each SWUC at the Fleet level. For the four SWUCs analyzed, this projection shows a total cost of $3,489,027 in FY 1977 $. Escalating to FY 1979 $ would result in a total cost of $3,977,491 for Potentially Avoidable Maintenance of these SWUCs[7]. Were the costs associated with No-Repairs-Required actions at the depot included, a larger estimate would result.

From this analysis of a limited number of Work Unit Codes, it becomes obvious that if the total Navy aircraft inventory were considered, the costs of PAM would be significantly greater.

3.2.3.4.3 A-7E (WUC 73) NOR Projection

Before the NOR impact could be assessed for the A-7E, it was necessary to scale upward its estimated PAM impact to compensate for the partial performance of the Induced Defect

analysis. This was accomplished as follows. Using Tables 10 and 11, a weighted average proportion (for the F-14A and S-3A avionics) of PAM NOR time associated with the Induced Defect program was calculated. The result was that on the average 35% of the total PAM NOR time was disclosed by this portion of the Induced Defect analysis. The PAM NOR time disclosed by the programs executed for the A-7E was scaled according to this proportion to yield an estimate of the total NOR time. This calculation was accomplished as follows:

$$\text{ESTIMATED PAM NOR TIME}_{\text{(A-7E/WUC 73)}} = \frac{1{,}836.6}{.65} \text{ (From Table 17)}$$

$$= 2{,}826 \text{ Hours}$$

3.2.3.5 <u>Relative Impact of Potentially Avoidable Maintenance</u>

The action quantity, cost, and NOR time impacts of the Potentially Avoidable Maintenance identified for each SWUC were estimated relative to the action quantity, cost, and NOR time totals associated with all maintenance actions on that WUC.

The action quantity impact presented in Table 22 for each SWUC was computed as the ratio of PAM actions on that WUC for CNAL squadrons to all actions on that WUC for CNAL squadrons. Both of these quantities are as identified by ISI information processing. The A-7E estimate of PAM action quantity was obtained via projection by the method described in Sections 3.2.3.4.1 and 3.2.3.4.3. Using action quantities, the resulting divisor is .88.

The cost impact presented in Table 23 for each SWUC was computed as the ratio of the Fleetwide PAM cost estimate, obtained

TABLE 22. RELATIVE IMPACT OF PAM ON ACTION QUANTITY

	T/M/S/SWUC	F-14A/74	S-3A/73	S-3A/13	A-7E/73
1	CNAL PAM ACTIONS (QTY)	2,529	4,129	696	4,644*
2	CNAL TOTAL ACTIONS (QTY)	12,600	20,956	5,186	25,349
	RELATIVE IMPACT (%)	20.1	19.7	13.4	18.3

* Partial projection

TABLE 23. RELATIVE IMPACT OF PAM ON MAINTENANCE COST

	T/M/S/SWUC	F-14A/74	S-3A/73	S-3A/13	A-7E/73
3	FLEET PAM COST ($)	665,952	1,011,546	283,749	1,527,780
4	FLEET TOTAL MAINTENANCE COST ($)	6,884,000	18,572,000	9,703,000	17,366,000
	RELATIVE IMPACT (%)	9.7	5.4	2.9	8.8

1 From Tables 14. (F-14A/74), 15. (S-3A/73), 16. (S-3A/13), Para. 3.2.3.5 (A-7E/73)

2 From Table 4, Item 6

3 From Table 20, Column 9

4 From FY 1977 VAMOSC MS, scheduled and unscheduled

in Section 3.2.3.4.2, to the total Fleetwide maintenance cost, obtained from the FY 1977 VAMOSC MS.

The NOR impact of Potentially Avoidable Maintenance as presented in Table 24 was estimated for each of the SWUCs as follows. First, the PAM NOR Time (Column 1) was converted to the PAM NOR Rate (Column 2) by dividing by the Readiness Reporting Hours for CNAL squadrons obtained from AMPAS data[3]. The PAM NOR Rate represents the proportion of the time an aircraft is down due to Potentially Avoidable Maintenance on a given WUC. Another way to view this parameter is as follows. If there were no PAM on other WUCs on the aircraft and no NOR time associated with legitimate maintenance actions, the NOR Rate for each T/M/S would be the corresponding value in Column 2.

To place the values of PAM NOR Rate in the proper perspective, the Overall NOR Rates associated with each WUC and its parent aircraft T/M/S are presented, as obtained from AMPAS data, in Columns 3 and 5 respectively[3]. The contribution of Potentially Avoidable Maintenance to the Overall NOR Rate was computed for each SWUC as the ratio of PAM NOR Rate, SWUC (Column 2), to the Overall NOR Rate, SWUC (Column 3). The result is presented in Column 4 for each SWUC.

The significance of each SWUC, in terms of NOR Rate, to its parent aircraft T/M/S was quantified by computing the ratio of the Overall NOR Rate, SWUC (Column 3) to the Overall NOR Rate, T/M/S (Column 5). The result is presented in Column 6 for each SWUC.

TABLE 24. SUMMARY OF POTENTIALLY AVOIDABLE NOR

T/M/S/SWUC	(1) PAM NOR, SWUC, CNAL TIME (HRS)	(2) PAM NOR, SWUC, CNAL RATE (%)	(3) OVERALL NOR RATE, SWUC, CNAL (%)	(4) PAM NOR, % OF OVERALL SWUC NOR RATE (%)	(5) OVERALL NOR RATE, T/M/S, CNAL, (%)	(6) SWUC NOR RATE, % OF T/M/S NOR RATE (%)
F-14A/74	3,580	.64	3.5	18.3	50.0	7.0
S-3A/73	5,964	1.1	3.8	28.9	52.0	7.3
S-3A/13	1,906	.35	2.2	15.9	52.0	4.2
A-7E/73*	2,826	.21	2.0	10.5	33.3	6.0

(1) From Tables 14. (F-14A/74), 15. (S-3A/73), 16. (S-3A/13), Para. 3.2.3.4.3 (A-7E/73)
(2) From (1) and Reference 3
(3) From Reference 3
(4) Columns (2) divided by (3)
(5) From Reference 3
(6) Columns (3) divided by (5)

* Partial projection

3.3 Summary of Results

The following paragraphs summarize results of the analysis previously described in this section.

3.3.1 Built-In Test (BIT)

The dependability of BIT on the S-3A avionics was examined and compared to the dependability goals expressed in the specification[27]. The results were that the sensitivity level of the BIT appears to be excessively low. That is, the False Alarm Rate (6.1%), while higher than the goal (1%), is much lower than the No-Repairs-Required Rate associated with diagnosis unaided (as identified by How Malfunctioned Codes) by BIT (39.0%). On the other hand, the Failure Location Rate (25.7%) appears to be much lower than the goal (95%). This finding, while significant, is somewhat mitigated by possible maintenance data reporting practices and maintenance procedures. Firm conclusions can only be drawn after field investigations have been conducted to clarify these practices and procedures.

3.3.2 Failure-To-Fault-Isolate

Using only suffixed I-Level maintenance actions as reflective of the I-Level diagnostic process, the efficiency of that process was evaluated for all of the selected WUCs of this study. Two observations resulted from this analysis. First, there is no indication that the mechanical WUC analyzed, the landing gear on the S-3A (WUC 13), has an SRA-level diagnostic problem. There appears to be no ambiguity at that level as to which component(s)

is (are) faulty.

Second, the avionics on the mature aircraft under study, the A-7E, appears to have a significantly lesser SRA-level diagnostic problem (2.0% error rate) than the more modern avionics of the S-3A and F-14A (error rates of 11.9% and 16.6% respectively).

Three alternative explanations are proposed for the latter observation. First, the relative complexity of the more modern avionics may result in more diagnostic problems, even with the aid of BIT. Second, maintainability improvements incorporated into the A-7E, and experience gained by its maintenance organization, may have resulted in a lesser diagnostic problem than is experienced by the newer aircraft (S-3A and F-14A). Third, the use of automatic test by the IMA for these newer aircraft may have the following effect. If the person who identifies potentially faulty SRAs is not the same person who attempts to repair them, the coding of false removals (ATC A) may occur more frequently. A person who repairs an SRA which he isolated in the conventional manner might be reluctant to report his error.

3.3.3 Cost/Down Time of Potentially Avoidable Maintenance

There are two perspectives from which to evaluate the impact of PAM—absolute and relative. In absolute terms, the study estimated that, in FY 1979 dollars, at least $4.0 million can be attributed to PAM actions on the Subject Work Unit Codes (SWUCs) during FY 1977. As shown in Table 25, the total quantity of Unscheduled Maintenance Actions (UMAs) generated by the SWUCs

TABLE 25: <u>UNSCHEDULED MAINTENANCE ACTION (UMA) SUMMARY</u>

T/M/S/SWUC		FLEETWIDE UMA SWUC[29]	FLEETWIDE UMA T/M/S[31]
F-14A	SWUC 74	25,588	
	T/M/S		164,254
S-3A	SWUC 73	37,889	
	SWUC 13	13,584	
	TOTAL	51,473	
	T/M/S		159,970
A-7E	SWUC 73	50,268	
	T/M/S		287,791
TOTAL	SWUCs	127,329	
	T/M/S		612,015

TOTAL NAVY INVENTORY[31]	3,731,894

TABLE 26. RELATIVE IMPACT OF POTENTIALLY AVOIDABLE MAINTENANCE TO TOTAL MAINTENANCE

T/M/S/WUC	ACTION CONTRIBUTION (%)	COST CONTRIBUTION (%)	NOR CONTRIBUTION (%)
F-14A/74	20.1	9.7	18.3
S-3A/73	19.7	5.4	28.9
S-3A/13	13.4	2.9	15.9
A-7E/73	16.1	8.8	10.5

Notes: Percentages exclude the impact of depot No-Repairs-Required actions.

Action (and cost) percentages computed as fleetwide estimated PAM actions (and cost) ÷ total maintenance actions (and cost), for the same subsystems, from FY 77 VAMOSC MS.

NOR percentages computed as CNAL PAM NOR time ÷ CNAL total maintenance NOR time, for same subsystem, from FY 77 hard-copy AMPAS data.

during FY 1977 is 127,329 and the total quantity of UMAs for the three complete parent aircraft T/M/S is 612,015.

Thus, only 21% of the UMAs associated with these aircraft were investigated relative to Potentially Avoidable Maintenance. It should be further noted that for the total Navy aircraft inventory, there were 3,731,894 UMAs during FY 1977 and, thus, only 3.4% of the Navy UMAs were considered by this study. Therefore, the Potentially Avoidable Maintenance revealed by this study may be only the "tip of the iceberg."

In addition, the study estimated that at least 14,276 hours of NOR time can be attributed to Potentially Avoidable Maintenance on the SWUCs by the squadrons of the Commander of Naval Air Force, U.S. Atlantic Fleet (CNAL) during FY 1977. The CNAL squadrons generated about one-half of the fleetwide UMAs, making this NOR time estimate an even smaller sample.

From the relative viewpoint, the proportion of total maintenance—actions, cost, and NOR time—attributable to PAM were computed and are presented in Table 26. They indicate that from 13% to 20% of all maintenance actions could be prevented, with the accompanying reduction in maintenance cost and down time, if appropriate investments were made in maintenance improvement.

3.3.4 Level of Confidence in Results

The estimates of PAM action quantity, cost, and down time resulting from this study are <u>highly conservative</u> for the following

reasons, some of which were discussed earlier. PAM actions occurring at the depot were excluded from the study because of the exclusion of depot maintenance from the MDR system. This may be a significant category of Potentially Avoidable Maintenance.

The maximum time separation allowed to exist between pairs of maintenance actions in order to be considered potentially related was between two and three days for the various PAM categories. These time "windows" were chosen arbitrarily, but are so small as to ensure that the actual quantity and impact of PAM actions are greater than the estimates obtained by this study. For instance, the intervention of a weekend could cause a string of related actions to be broken. This limitation might be alleviated by the use of flying hours, rather than days, for the time criteria. Such flying-hour tracking would involve interfacing with flight data records.

There are other ways in which PAM actions could escape detection by the inferential logic. If a maintenance technician incorrectly enters the part serial number on the MAF and the equipment is returned defective to supply, because I-Level maintenance either failed to correct the defect or induced it, the error is not traceable. If an item of equipment in this condition sits on the shelf for several days and does not have an elapsed-time meter or the meter time is not properly entered on the MAF, the error will escape detection because the subsequent maintenance action will be outside of the "window." Another way in which a PAM action can escape detection is the following. A technician who induces a defect during maintenance and is aware of his error

may correct it at that time with hardly a trace showing in the data system. If the induced defect occurs during what would otherwise have been a No-Repairs-Required action, the technician may code it as a corrective action. This practice would reduce the observed quantity of No-Repairs-Required actions as well.

Data validity is another area that resulted in conservative estimates. Specifically, since AMPAS data tapes provide the removal date for the O-Level action date of a remove-and-replace action, it is expected that the O-Level date would always precede the I-Level date. The reversal of this date order is one of several reasons for which records were eliminated by tape preprocessing programs. The motivation for eliminating such records was that a record with obviously erroneous data is unreliable.

It was discovered during processing that a large proportion of rejected records were eliminated because of date reversal. Two likely explanations for this phenomenon are the failure of O-Level technicians to properly fill out a MAF or the failure of keypunchers to transcribe the removal action date to the remove card—Card Type 26. If the dates are correct on the MAF, the keypunchers may be transcribing the replacement date. On the S-3A, which is notable for its supply problem during the time frame of this study, and on the F-14A, it is possible that the IMA frequently completes corrective action before the O Level can replace the equipment, thus making the data error visible.

The impact of this problem was the reduction in detection of PAM actions involving remove-and-replace or remove-and-reinstall,

resulting in the elimination of an indeterminate number of sequences of related actions. The only categories unaffected are the O-Level No-Repairs-Required actions and Failure-To-Acknowledge. The category likely to be most affected is Failure-To-Diagnose since only remove-and-replace actions are involved. Indeed, few (if any) instances of Failure-To-Diagnose were detected.

Down-time estimates obtained by this study are conservative for the following reason. If an aircraft is down (i.e., unable to perform any primary mission) due to scheduled maintenance for less than two hours, it is not reported NOR due to scheduled maintenance (NORMS).

Finally, the hourly labor rate applied to labor cost computations includes only the direct costs of pay and allowances. This was appropriate to an analysis intended to determine the cash-flow impact of Potentially Avoidable Maintenance. Billet cost factors, however, reflect the personnel "life cycle" costs (direct and indirect), incurred in filling a position, or billet, e.g., recruitment, training, retirement, etc. These cost elements should be considered in an economic analysis. They are more inclusive and, therefore, significantly greater in value.

In general, the limitation of an inferential technique, such as the one used for this analysis, is that there are two types of error, one of which inevitably increases with efforts to reduce the other. One type—which will be called inclusion error—occurs when a legitimate maintenance action, or group thereof, is determined to be potentially avoidable because it coincidentally satisfies the criteria of inference.

The other type—which will be called exclusion error—is the failure to identify true PAM actions because they do not quite satisfy the criteria. Weakening the criteria sufficiently would reduce the rate of exclusion error, but it would also increase the rate of inclusion error. This is because weakened criteria allow more legitimate <u>and</u> potentially avoidable actions to be identified as potentially avoidable. The opposite effect occurs when the criteria are strengthened.

In designing the algorithms, selecting time criteria, and estimating input parameter values, a very conservative approach was taken so that the case for maintenance improvement would not be overstated and so that estimates obtained for potentially avoidable cost and down time would unquestionably be lower bounds.

4.0 RECOMMENDATIONS

Based on the findings of this investigation, the following recommendations are offered.

- Since it is reasonable to suppose that all of the Services experience Potentially Avoidable Maintenance problems, each Service should investigate application of this or similar approaches to complement their on-going maintenance improvement efforts.

4.1 Data-Base System Improvements

- Field investigations should be conducted to determine the maintenance and reporting practices observed with respect to Built-In Test (BIT) at the O Level. If it is the practice of O-Level maintenance to verify BIT indications before transferring an assembly to the I Level, then the O Level is making the False Alarm Rate appear less than it actually is.

- If it is the practice of O-Level maintenance to enter the How Malfunctioned Code (HMC) indicating the suspected cause of a defect or code 799, indicating No Defect, then a revision of the Maintenance Data Reporting (MDR) forms or the procedures for completing them should be modified as necessary to allow accurate monitoring of BIT performance. In particular, maintenance technicians should be instructed to enter a BIT HMC when the suspected faulty assembly is located with the aid of BIT. An alternative

is to revise the forms as necessary to include a "Diagnostic Technique Code." This code would indicate whether BIT, Automatic Test Equipment, or conventional means were utilized in the diagnostic process.

- To facilitate the detection of Failure-To-Diagnose actions, it is recommended that the O-Level date of remove-and-replace actions be consistently coded and keypunched into the Maintenance Data Reporting system. Toward this end, the Navy should investigate the feasibility of adding a validation specification to the NALCOMIS data entry subsystem for maintenance.

- To facilitate the determination of the extent to which Potentially Avoidable Maintenance occurs at the depot, a desirable goal is to incorporate the Government Depots into the MDR system. This would provide single-thread tracking of maintenance actions through the maintenance cycle.

4.2 Further Study

- In the interim, the feasibility of determining, through field investigations, the extent, causes, and impact of Potentially Avoidable Maintenance occurring at the Government depots should be explored.

- Follow-up field investigations should be conducted to determine the causes of PAM problems pinpointed to

specific assemblies, as demonstrated by this study. When these causes are determined, potential solutions should be identified and their cost and effectiveness estimated. The solutions should then be implemented in those cases in which they are found to be cost-effective.

- It is recommended that further analysis be conducted to identify the degree to which each causative factor of Potentially Avoidable Maintenance would respond to investment in improvements aimed at reducing the cost/down time of PAM. These underlying causes would include training and skill deficiencies, hardware problems, documentation problems, and support equipment shortcomings.

- It is recommended that a model structure be developed, incorporating the results of the previous recommendation, and that it be applied to the determination of economically sound investment decisions, for a weapon system currently in the planning stages, relative to improvement of the maintenance process.

4.3 Enhancement of Analytical Technique

- To assess the contribution of I-Level diagnosis to the PAM problem, the Failure-To-Fault-Isolate category chould be incorporated into the computerized search system.

- To reduce the rate of exclusion error (failure to capture Potentially Avoidable Maintenance actions) of the search

algorithms, it is recommended that the feasibility of implementing flying-hour tracking be explored.

- In the interim, or as an alternative to flying-hour tracking, consideration should be given to the conservative nature of the criteria used for the present study and the quantity of Potentially Avoidable Maintenance uncovered. Perhaps even greater quantities would be inferred with time "windows" of three (3) or four (4) days, to account for weekends of inactivity.

- It is recommended that until the earlier recommendation regarding the coding and keypunching of action dates can be implemented revisions be made to the computerized algorithms to account for the fact that a large proportion of O-Level remove-and-replace actions are assigned the wrong action date. This would be expected to result in detection of a greater quantity of Potentially Avoidable Maintenance, and could result in a significant increase in the Failure-To-Diagnose category.

4.4 Further Analysis

- Having found the relative NOR impact of Potentially Avoidable Maintenance to be greater than the relative cost impact, it is recommended that the analysis reported here be performed for the subsystems (two-digit WUCs) most critical to each weapon system's operational status.

In particular, the highest NOR-contributing subsystems for each aircraft studied and its relative contribution, based on Fiscal Year 1977 hard-copy AMPAS data, is:

T/M/S	WUC	SUBSYSTEM	WUC NOR ÷ T/M/S NOR
F-14A	23	TURBOFAN ENGINE	15.6%
S-3A	14	FLIGHT CONTROLS	19.2%
A-7E	23	TURBOFAN ENGINE	23.0%

- To more accurately estimate the fleetwide impact of Potentially Avoidable Maintenance, it is recommended that the same analysis as reported here be conducted for the squadrons of the Commander of Naval Air Force, U.S. Pacific Fleet (CNAP). Further, similar analyses should be conducted on sample Air Force and Army aircraft.

- To speed and knowledgeably focus the response to unfavorable deviations of field reliability and maintainability of newly deployed weapon systems from specified or desired values, it is recommended that the analytical system developed under this study, and enhanced as recommended above, be executed early in the operational phase of all new weapon systems. Further, the specific causes of problems pinpointed thereby should be identified and the economic model, developed as recommended above, be applied to determine a sound investment program for maintenance improvement. To measure the success of

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such improvement programs, the occurrence of Potentially Avoidable Maintenance should be monitored during their implementation via regular execution of the analytical system.

- To facilitate implementation of the previous recommendation, the feasibility of identifying physical and functional relationships among assemblies during the acquisition process should be explored. The assemblies considered for identification as subject to Potentially Avoidable Maintenance should be restricted to those whose counterparts on existing operational aircraft have experienced Potentially Avoidable Maintenance.

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THE ECONOMICS OF MAINTENANCE IMPROVEMENT FEASIBILITY STUDY

(Phase I)

Milton Clyman
Philip S. Grenetz
Richard S. Shultz

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Prepared for:

Department of Defense
OASD (MRA&L)
Pentagon - Room 2B323
Washington, D.C. 20301
Attention: Lt. Col. Roger Grossel

1745 JEFFERSON DAVIS HIGHWAY
ARLINGTON, VIRGINIA 22202
(703) 521-1050

955 LOUIS DRIVE
WARMINSTER, PA. 18974
(215) 674-8022

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This interim report presents the results of research into the feasibility of assessing the economic (cost and downtime) impact of unnecessary maintenance actions, such as false alarms, induced defects, and failure-to-repair. The goal of the study of the economics of maintenance improvement is to develop techniques to assist in allocating resources, during the acquisition phases of weapon system programs, to Built-In Test, spares, personnel, etc., so as to minimize their life cycle economic expense with respect to unnecessary maintenance.

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THE ECONOMICS OF MAINTENANCE
IMPROVEMENT FEASIBILITY STUDY (PHASE I)

EXECUTIVE SUMMARY

Today the armed services incur costs for Operation and Support (O&S) of airborne weapon systems which represent a continually increasing proportion of the defense budget. Unnecessary unscheduled maintenance actions contribute a large share of this O&S expense. A review of Visibility And Management Of Support Costs (VAMOSC) data across many active Naval aircraft reveals a consistent ratio around 2:1 of unscheduled maintenance actions to failures associated with unscheduled maintenance. A recent GAO study report on weapon system O&S cost trends cited induced defects and depot false alarms (reported as failures by the Maintenance Data Collection System) as two of the main factors responsible for specification-to-field reliability degradation.

Avoidable maintenance actions and excessive delays in the maintenance cycle result also in increased logistics requirements and costs, e.g., pipeline spares and support equipment. This unnecessary maintenance also inevitably causes a decline in the weapon system's utility as measured by a higher Not Operationally Ready (NOR) rate.

Purpose

The goal of the study of maintenance improvement is to develop techniques (economic model(s)) for allocating resources (e.g., Built-In Test (BIT), spares, personnel), in the RDT&E and Procurement phases of new weapon system programs so as to minimize life cycle cost and downtime with respect to prevention of unnecessary

20. The report details the process by which the appropriate data sources for economic impact assessment were identified and applicable analytical techniques were formulated. It also provides the rationale by which the selection of a sample of aircraft T/M/S, WUCs, and squadrons should be made, for investigation under a demonstration study.

maintenance. The purpose of the present feasibility study was to formulate a practical approach to assessing the cost and downtime impact of avoidable maintenance actions. This included identification of problem areas, affected cost elements, data sources useful for quantifying selected problem areas, sample determination, and development of specific analytical techniques for the purpose of assessing the cost saving potential regarding maintenance improvement.

Scope

This study was limited to the utilization of data in the possession of Information Spectrum, Inc. upon contract initiation. On-site interviews were limited to local Navy and Air Force installations. Evaluation of the available data sources and products was performed in order to determine those which would be most useful for the conduct of the maintenance improvement study.

It was determined that the aircraft Type/Model/Series (T/M/S) and associated Work Unit Codes (WUCs) most beneficial for study in Phase II are:

- F-14A, WUC 74
- F-4J, WUC 74
- S-3A, WUCs 13 & 73

It was demonstrated during this phase of the study that there is a feasible approach to the identification of unnecessary maintenance actions, the assessment of their resulting cost and downtime impact, and the quantification of the performance of BIT with respect to a selected 2-digit avionics WUC.

During the study a systematic approach was developed together with identification of the most significant subsystems to be analyzed in Phase II.

Conclusions

It was concluded that the significant problem areas to be addressed in Phase II are:

- False Alarm
  - Organizational Level
  - Intermediate Level
  - Depot Level
- Failure-To-Repair
  - Failure-To-Acknowledge
  - Failure-To-Diagnose
  - Failure-To-Correct
- Induced Defects
  - Operational
  - Maintenance
    - Organizational Level
    - Intermediate Level
  - Transportation/Handling

Recommendations

Considering the potential cost and downtime savings achievable by reducing the incidence of unnecessary maintenance, and considering the feasibility of implementing the technical approach as described in this report, it is recommended that the study of the economics of maintenance improvement proceed with Phase II. Further, it is recommended that, during Phase II, the analytical technique described in this report be implemented on a small-scale basis for demonstration purposes. In particular, the above aircraft T/M/S and 2-digit WUCs are recommended as subjects of this investigation.

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During the course of this feasibility study, the authors had the benefit of numerous constructive comments and review from persons in the Office of the Assistant Secretary of Defense (MRA&L), in particular Mr. Russell Shorey, Mr. Martin Meth, Lt. Col. Roger Grossel and Lt. Col. Donald Tetmeyer.

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LIST OF ABBREVIATIONS

AIMD	Aircraft Intermediate Maintenance Department
AMPCS	Analytical Maintenance Program Computer Support
ATC	Action Taken Code
AWM	Awaiting Maintenance
AWP	Awaiting Parts
BCM	Beyond Capability of Maintenance
BIT	Built-In Test
CASEE	Comprehensive Aircraft Support Effectiveness Evaluation
CBS	Cost Breakdown Structure
D	Depot
EMT	Elapsed Maintenance Time
GSE	Ground Support Equipment
HMC	How Malfunctioned Code
I	Intermediate
ICRL	Individual Component Repair List
IMA	Intermediate Maintenance Activity
IMRL	Individual Material Readiness List
JCN	Job Control Number
LOR	Level Of Repair
MA	Maintenance Action
MAF	Maintenance Action Form
M/D/S	Mission/Design/Series
MMH	Maintenance Man-Hours
MTTR	Mean Time To Repair

LIST OF ABBREVIATIONS
(Continued)

NAMP	Naval Aviation Maintenance Program
NOR	Not Operationally Ready
NORMU	Not Operationally Ready - Unscheduled Maintenance
NORS	Not Operationally Ready Supply
NRTS	Not Reparable This Station
O	Organizational
OR	Operational Readiness
ORLA	Optimal Repair Level Analysis
O&S	Operating and Support
RFI	Ready For Issue
RMCMU	Reduced Material Condition - Unscheduled Maintenance
RMCS	Reduced Material Condition Supply
SM&R	Source, Maintenance & Recoverability
SRA	Shop Replaceable Assembly
SRU	Shop Replaceable Unit
T/M/S	Type/Model/Series
VAMOSC	Visibility And Management Of Support Costs
WDC	When Discovered Code
WRA	Weapon Replaceable Assembly
WUC	Work Unit Code
3-M	Maintenance and Material Management

1.0 INTRODUCTION

Today the armed services incur costs for Operation and Support (O&S) of airborne weapon systems which represent a continually increasing proportion of the defense budget[1]. Unnecessary unscheduled maintenance actions contribute a large share of this O&S expense. A review of Visibility And Management Of Support Costs (VAMOSC) data across many active Naval aircraft reveals a consistent ratio around 2:1 of unscheduled maintenance actions to failures associated with unscheduled maintenance. A recent GAO study report on weapon system O&S cost trends cited induced defects and depot false alarms (reported as failures by the Maintenance Data Collection System) as two of the main factors responsible for specification-to-field reliability degradation[1].

Avoidable maintenance actions and excessive delays in the maintenance cycle result also in increased logistics requirements and costs, e.g., pipeline spares and support equipment. This unnecessary maintenance also inevitably causes a decline in the weapon system's utility as measured by a higher Not Operationally Ready (NOR) rate.

The objective of the present feasibility study is to demonstrate a practical approach to assessing the cost and downtime impact of avoidable maintenance actions. The goal of the study of maintenance improvement is to develop techniques (economic model(s)) for allocating resources (e.g., Built-In Test (BIT), spares, personnel), in the RDT&E and Procurement phases of new weapon system programs so as to minimize life cycle cost and downtime with respect to prevention of unnecessary maintenance. This report documents the Phase I study of

the feasibility of achieving the present objective. Specifically, it presents background information compiled during the study, supportive data extracted from sources available at the beginning of the study, a practical rationale applicable to identification and cost/downtime assessment of each type of unnecessary maintenance action deemed feasible to study, and the data requirements for a demonstration project. Appendix C contains a recommended plan of action for the conduct of the demonstration (Phase II) project.

2.0 BACKGROUND

The following paragraphs provide detailed background information regarding the nature of the unnecessary maintenance problem, the specific cost elements involved, and the data sources available.

2.1 Classification of Causes of Unnecessary Maintenance

The causes of preventable maintenance actions and delays are numerous. Many problems are design related. Faulty design can result in a high rate of endogenous failure—primary and secondary failure due to wear, corrosion, electronic drift, burnout, etc.—and excessive removal, replacement, and repair times[2]. Poor design is often responsible for fault isolation difficulty and physical interference with one or more equipments encountered during the removal or installation of another equipment[3,4].

Allocation of support resources in a less-than-optimal manner can result in long delays and an excessive number of transfers to depot maintenance. Whenever an item of equipment is sent to the depot, transportation, handling, and bookkeeping costs are incurred. Moreover, the labor rate for depot maintenance is generally higher than that for intermediate level maintenance. The turnaround time associated with depot maintenance (generally about 30 times that of local maintenance) necessitates an increased requirement for pipeline spares and/or acceptance of a higher NOR rate. Additionally, associated with every transfer is the probability that damage will be incurred in shipping and/or handling.

Maintenance policy is another contributor to depot transfers. Prior to reaching initial operational status, a weapon system is

subjected to an Optimal Repair Level Analysis (ORLA), which determines the most economical means by which to support the system. Among other decisions based on the ORLA, each Weapon Replaceable Assembly/Line Replaceable Unit (WRA/LRU) and Shop Replaceable Assembly/Shop Replaceable Unit (SRA/SRU) is designated reparable or consumable. In addition, each assembly designated reparable is identified as to the maintenance levels at which it is to be repaired. This is based in part on maintenance action frequencies, the higher depot repair cost, and the higher cost of placing support equipment at the Organizational & Intermediate (O&I) levels. Throughout the operational buildup period of a weapon system, the ORLA should be periodically updated, based on maintenance action frequencies experienced in the field. If an item requires maintenance frequently enough, it could be more economical to provide intermediate level maintenance with sufficient resources and repair authorization.

Some problems are caused by human error. While their rate of occurrence and/or impact can be reduced through careful hardware design, the human being is responsible[3,4]. Operationally induced maintenance actions include those resulting from excursions of the aircraft beyond the flight envelope, hard landings, careless and abusive operation, and unwarranted aircrew and ground crew gripes. Maintenance-induced problems include poor fault isolation technique ("shotgun", trial-and-error, etc.), failure to test after a repair action, careless removal and installation, abusive treatment, and unnecessary discards. Transportation and handling errors include damage caused in transit between depot and base, between supply and maintenance crews, and between organizational maintenance and the aircraft.

For the purposes of this study, those problems for which hardware design is exclusively responsible—poor inherent reliability—have been eliminated from consideration. The specific problem areas considered during the feasibility study are listed in Table I, by the acronyms used elsewhere in this report.

TABLE I. SPECIFIC PROBLEM AREAS

ACRONYM	DESCRIPTION
BCM/NRTS*	Excessive transfers to depot maintenance
AWM/AWP	Delays awaiting maintenance and parts
DIAG/REPR	Excessive Maintenance Man-Hours (MMH) to diagnose and repair a defect
OID	Operationally induced defects
MID	Maintenance-induced defects (O,I, & D levels)
FTR	Failure-to-repair a defect (O,I, & D levels)
FA	False alarms (discovered by O,I, & D levels of maintenance)
UWD	Unwarranted discards (I&D Levels)

* Action Taken Code (ATC) 1 through 9 are designated Beyond Capability of Maintenance (BCM) by the Navy and Not Reparable This Station (NRTS) by the Air Force.

2.2 Maintenance Policies and Forms

Several questions were posed to provide background information relating to the areas of maintenance policy highlighted by the study of maintenance improvement. To answer these questions, several sources were consulted[5,6,7,8,9]. Included among these sources are in-house personnel with field experience; the maintenance officer, production chief, supply (component control) personnel at the Willow Grove Naval Air Station; and the Quality Assurance Superintendent at the Air National Guard 177th Fighter Interceptor Group at Atlantic City.

It was determined that, for the Navy, reparability and authorization of Intermediate Maintenance Activity/Aircraft Intermediate Maintenance Departments (IMA/AIMDs) to repair are identified by the Source, Maintenance, & Recoverability (SM&R) code of each item. This code consists of six (6) characters. The character in the fourth position determines reparability and authorization. An item is coded "Z" or "B" if it is not reparable, "B" implying a degree of adjustability. The code "D" indicates that only the depot is authorized to repair the item. Authorization of IMA/AIMDs to repair an item may be assigned on a selective basis to certain organizations, depending on their capabilities (e.g., skills and manpower), Ground Support Equipment (GSE) authorization, and other resources. The code "L" denotes this selective authorization. The SM&R codes and the maintenance organizations authorized to repair those items coded "L" are contained in the Individual Component Repair List (ICRL), which is updated quarterly. The set of GSE items which are authorized for use by each maintenance organization is compiled in the Individual Material Readiness List (IMRL).

For both the Air Force and the Navy, notwithstanding the difference between the Action Taken Code definitions appearing in their respective Work Unit Code (WUC) books (as shown in Appendices A & B), an equipment which has been griped and cannot be maintained at the intermediate level for any reason will be tested, if possible, to verify failure before sending it to the depot. In the case of the Navy, it is not required by Navywide policy to test an item prior to an ATC 1 (Repair Not Authorized) action. It is generally, however, local policy to do so. It was learned that a Navy AIMD will, if expeditious and economical, transfer a defective item to another AIMD which has the capability and authorization to repair the item rather than send it to the depot. This action results in the same ATC which would be entered were the item transferred to the depot.

In the Navy, an ATC 1 is entered on the Maintenance Action Form (MAF) when an item is not reparable at the IMA/AIMD because GSE, tools, or facilities are unavailable due to lack of authorization. In the Air Force, an ATC 2 is entered whenever non-reparability of an item results from insufficient GSE, tools, or facilities, whether or not the requisite resources are authorized. This distinction between the policies of the two services has implications for data interpretation. It also may render some Navy IMA/AIMD personnel less likely to generate an ATC 2 action because such an action could reflect badly on the quality of maintenance and care of GSE and tools.

Regarding the maximum time delays forecast to be sustained by intermediate maintenance Awaiting Maintenance (AWM) for backlog (i.e., insufficient personnel) or Awaiting Parts (AWP) before

deciding to send the item to the depot, the Naval Aviation Maintenance Program (NAMP)[9] establishes a 30 day limit on parts for the Navy. The Air Force limits are established by AFM 67-1, Volume II, Part One, Chapter 17. The Navy's limit is often extended by local practice to 60 days because the IMA/AIMD prefers to retain all equipments in their possession. ATC 5 (Backlog), regardless of its severity, is seldom coded because it may be taken as an indication of sub-optimal efficiency. Similarly, ATC 3 (Insufficient Skills) is seldom coded because, for an organization which is authorized to repair and, therefore, is expected to have the capability, the Insufficient Skills code might be an indication of sub-par quality of maintenance.

Finally, ATCs, When Discovered Codes (WDCs), and How Malfunctioned Codes (HMCs) were reviewed to identify those codes which could be utilized to infer incidences of unnecessary maintenance. "No Repair Required" is coded Action Taken A and H* by the Navy and Air Force, respectively. All HMCs entered in conjunction with "No Repair Required" which indicate corrective action of some type can be interpreted as a False Alarm leading to adjustment to optimize performance. HMC 799—"No Defect"—entered in conjunction with "No Repair Required" is also interpretable as a False Alarm. This also applies to HMC 948—"No Defect, Operator Error"—used solely by the Air Force. When Navy personnel enter HMC 437—"Improperly Positioned, Selected, or Other Operator Error"—in conjunction with ATC A, the interpretation of Operator-Induced False Alarm is similarly made.

HMCs 290 to 294—"Fails Automatic Tests"—or 607—"No Go Indication, Specific Reason Unknown"—entered at the organizational

*The Air Force codes ATC H for "On-Equipment" and B for "Off-Equipment" maintenance.

level, for a complaint subsequently coded as a False Alarm at the intermediate level, indicates poor fault isolation and/or degraded BIT performance. The Navy's HMC 811—"No Defect, Removed During Troubleshooting"—and the Air Force's HMC 812—"No Defect, Indicated Defect Caused by Associated Equipment Malfunction"—are indicative of diagnostic difficulty caused by some combination of human and hardware design error.

Entry of HMC 602—"Failed or Damaged Due to Malfunction of Associated Equipment"—suggests the occurrence of a secondary failure, which is beyond the scope of the present study. However, there exist HMCs which (when used) directly indicate the occurrence of a Maintenance-Induced Defect. In particular, these codes are 246—"Improper or Faulty Maintenance"—and, for the Air Force only, 033—"Destroyed or Removed From Service as a Result of Testing." Operator-Induced Defect is directly implied by the entry of HMC 931—"Accidental or Inadvertent Operation, Release, or Activation"—or the Navy's code 437 (specified above) entered in conjunction with a corrective ATC. Other HMCs which directly indicate the occurrence of induced damage are 086—"Improper Handling"—and 877—"Transportation Damage."

There exist exogenous causes of failure which are outside the control of human beings, even the designer. For example, HMCs 731—"Battle Damage"— and 878—"Weather Damage"—are not considered induced defects for the study of maintenance improvement. There are a number of HMCs which, while they are associated with corrective action and indicate failure resulting from endogenous causes, they can be construed as implying Maintenance-Induced Defect when

a maintenance action with such a code is slightly preceded in time by a maintenance action on the same or physically related item of equipment with ATC B,C,P,Q,R,S,T,U, or Z. These HMCs are listed in Table II. WDC Y—"Upon Receipt or Withdrawal From Supply Stocks"—is another indication of preventable maintenance of some type. It may indicate a Failure-To-Repair, Operationally Induced Defect, Transportation/Handling-Induced Defect, or Maintenance-Induced Defect at any maintenance level.

2.3 Cost Elements Affected

This section introduces the Cost Breakdown Structure (CBS) developed for use in the study of the impact of maintenance improvement. The qualitative relationship between specific problem areas and specific cost elements is identified and the degree of availability of quantitative models for assessment of the impact of maintenance improvement is described.

2.3.1 Cost Breakdown Structure

The CBS compiled for this study is composed of those elements which are each impacted significantly by the occurrence of unnecessary maintenance of at least one type. The term "cost" is used here in the generic sense to include monetary cost and loss of utility, i.e., readiness. The organization of the structure is based on that provided by an LMI Study on Aircraft O&S Costs[10], and the definitions are as specified therein. The CBS is presented in Table III.

2.3.2 Cost/Problem Matrix

To assist in visualizing the relationships between the preventable maintenance problem areas previously shown in Table I

TABLE II. INFERRED MAINTENANCE-INDUCED DEFECT HOW-MAL CODES

Code No.	Description	Using Services
070	Broken, Burst, Ruptured, Punctured, Torn, Cut	AF, Navy
092	Mismatched-Electronic Parts, Wheel Halves, Etc.	AF, Navy
093	Missing Part	Navy
105	Loose or Damaged Bolts, Nuts, Screws, Rivets, Fasteners, Clamps, or Other Common Hardware	AF, Navy
106	Missing Common Hardware	AF, Navy
108	Broken, Faulty, or Missing Safety Wire or Key	AF, Navy
127	Adjustment or Alignment Improper	AF, Navy
135	Binding, Stuck, or Jammed	AF, Navy
160	Broken Wires, Defective Contact or Connection	AF, Navy
410	Lack of, or Improper Lubrication	AF, Navy
425	Nicked or Chipped	Navy
540	Punctured	AF
585	Sheared	AF, Navy
651	Air in System	AF, Navy
660	Stripped	AF
730	Loose	AF, Navy
750	Missing	AF
780	Bent, Buckled, Collapsed, Dented, Distorted, or Twisted	AF, Navy
865	Protective Coating/Sealant Missing or Defective	AF
884	Lead Broken	AF
910	Chipped	AF
935	Scored, Scratched, Burred, or Gouged	AF, Navy

TABLE III. COST BREAKDOWN STRUCTURE

SUPPORT INVESTMENT DEMAND
PIPELINE SPARES
SUPPORT EQUIPMENT
ORGANIZATIONAL
INTERMEDIATE
DEPOT
MAINTENANCE MANUALS
ORGANIZATIONAL
INTERMEDIATE
DEPOT
OPERATING AND SUPPORT COST
BELOW DEPOT MAINTENANCE
AIRCRAFT MAINTENANCE MANPOWER
MAINTENANCE MATERIAL
DEPOT MAINTENANCE
MANPOWER
MATERIAL
SECOND DESTINATION TRANSPORTATION
REPLENISHMENT SPARES
NOT OPERATIONALLY READY TIME
UNSCHEDULED MAINTENANCE
SUPPLY

and the cost elements of Table III, a matrix was constructed and appears in Table IV. The matrix has a row for every problem area and a column for every cost element. Every cell of the matrix is the intersection of a row and a column. Thus, every cell represents the impact of a specific problem area on a specific cost element. A cell contains a zero (0) if no significant impact is envisioned. A one (1) is entered if the element of cost increases with an increased rate of occurrence of the problem. A negative one (-1) appears in a cell if the cost decreases with an increased occurrence of the problem.

One conclusion which can be drawn immediately from considering Table IV is that the problem areas with the greatest impact are Operator-Induced Defect and Maintenance-Induced Defect. This is a qualitative assessment in that these are the problems which have an impact on the largest number of elements—all of them. On the other hand, the cost elements most sensitive to unnecessary maintenance, in the same qualitative sense (sensitive to all problems), are Pipeline Spares and NOR Time. It should be noted that these elements are both sides of the same coin. Suppose the rate of maintenance activity, unnecessary or otherwise, increases. If additional Pipeline Spares are not purchased, OR (Operational Readiness) degrades. If no decline in readiness is acceptable, then a considerable Pipeline Spares investment may be required. In general, there is an economic tradeoff between these two elements.

2.3.3 Problem Selection

To maximize the benefit achievable beyond the demonstration stage (Phase II) of the investigation of maintenance improvement economics,

TABLE IV. COST/PROBLEM MATRIX

COSTS	SUPPORT INVESTMENT DEMAND							OPERATING & SUPPORT COST						NOR TIME
	PIPELINE SPARES	SUPPORT EQUIPMENT			MAINTENANCE MANUALS			DEPOT		BELOW		TRANSPORTATION	REPLENISHMENT SPARES	
		O	I	D	O	I	D	LABOR	MATERIAL	LABOR	MATERIAL			
PROBLEMS														
BCM/NRTS 1	1	0	-1	1	0	-1	1	1	1	-1	-1	1	0	1
BCM/NRTS 2-8	1	0	-1	1	0	-1	1	1	1	-1	-1	1	0	1
AWM/AWP	1	0	0	0	0	0	0	0	0	0	0	0	0	1
DIAG TIME	1	0	0	0	0	0	0	1	0	1	0	0	0	1
REPR TIME	1	0	0	0	0	0	0	1	0	1	0	0	0	1
OID	1	1	1	1	1	1	1	1	1	1	1	1	1	1
MID	1	1	1	1	1	1	1	1	1	1	1	1	1	1
FTR	1	1	1	0	1	1	0	0	0	1	0	0	0	1
FA	1	1	0	0	1	0	0	0	0	1	0	0	0	1
UWD	1	0	0	0	0	0	0	0	0	0	0	0	1	1

and to minimize the risk associated with the effort, a judicious selection of problem areas to study must be made. A semi-quantitative criterion was applied to selection based on potential benefit and some subjective rationale was applied to the selection process based on feasibility.

The potential benefit criterion utilizes the Cost/Problem Matrix of Table IV. For each problem area, an importance score was computed by summing the elements of the matrix row corresponding to the problem area. This score reflects the net number of cost elements affected. The four problem areas with the highest scores were selected: Operator-Induced Defect, Maintenance-Induced Defect, Failure-To-Repair, and False Alarm. In addition to this criterion, the problems of ATC 1-8 actions on items requiring repair were rejected. As shown by the data of Table V, depot transfers due to insufficient resources are overshadowed by depot transfers due to lack of repair authorization (ATC 1). Some ATC 1 actions are necessitated for security reasons, contractual requirements (i.e., contract maintenance), and other pressing reasons. The remainder are determined by optimal LOR (Level Of Repair) considerations. ORLA techniques presently exist and, if updated continually throughout the operational buildup period of a weapon system, will account for the effects of field reliability trends on optimal repair levels. ATC 1-8 actions should still be considered in the maintenance improvement study, but only from the standpoint of the cost of depot transfers necessitated by induced defects and depot false alarms.

From the feasibility viewpoint, Unwarranted Discards were rejected due to the inability to define the point at which an item is

TABLE V. SAMPLE DEPOT TRANSFER DATA*

T/M/S	ITEMS PROCESSED	ATC 1	ATC 1-8	ATC 1/ATC 1-8 (%)
F-14A	1302	215	294	73
F-4J	45381	13697	15294	90
S-3A	19744	7398	9482	78
A-7E	40729	11758	12794	92
P-3C	33354	9379	11356	83

*Source: MSO Report No. 4790.A2245-01, Aviation Component Repair Report, January through June 1977.

beyond economical repair and the difficulty of observing the condition of equipment at the time of discard. ATC 9 actions should still be considered, but only from the standpoint of the cost of discards (including those surveyed at the depot) necessitated by induced defects.

Because of the unavailability of depot maintenance action data, study of the Depot Maintenance False Alarm problem will require on-site investigation. The available data, as portrayed in Figure 1, indicate that no-defect actions occur quite frequently at the I level of maintenance.* Moreover, as previously shown in Table V, a large percentage of items processed are sent to the depot, many possibly without bench testing. Therefore, Depot Maintenance False Alarm should be included in the investigation. On the other hand, due to the difficulty of obtaining reliable depot data on location and the unavailability of hard depot maintenance action data traceable back to the O&I levels, Depot Failure-To-Repair and Depot Induced Defect might best be ignored for the purposes of the present study. Indeed, it is to be hoped that depot maintenance is much more likely to correctly repair a defective item and much less likely to induce a defect than intermediate level maintenance, especially on those items which the manufacturer services via contract maintenance.

2.3.4 Cost Model Availability

In the area of monetary cost elements, there exist algorithms or simple formulas by which the impact of maintenance workload on each element can be estimated. These models vary in sophistication

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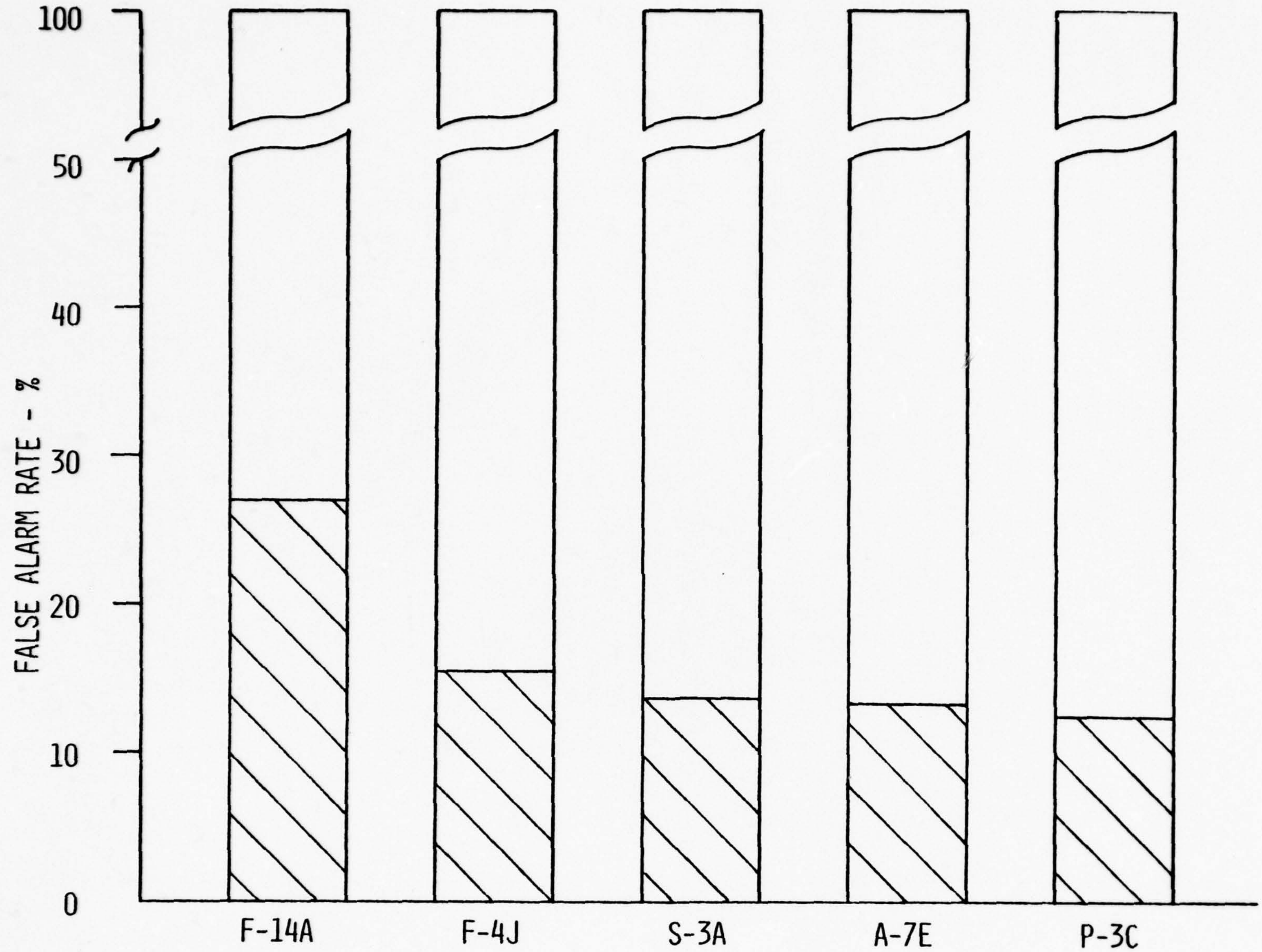
* NAVAIRDEVCEN MAINAC-FY 74, indicates for the F-4J that ATC A events are approximately 10% of all maintenance actions at the O level.



SOURCE: FY 76 VAMOSC-MS

Figure 1. False Alarm Proportion of I-Level Maintenance Actions

from simple cost per action and cost per man-hour factors for O&S cost elements to probabilistic inventory and queueing models for Support Investment elements based on the acceptable risk of stock-out or queue formation (derivable from WUC allocated NOR rates).

The Support Investment items are, in general, discretely procured resources determined by a continuously measurable demand. That is, continuous workload variables, such as maintenance action frequencies and turnaround time, determine the requirement for support resources, such as support equipment, which is purchased in discrete quantities—one set, two sets, etc. Since the various users of the equipment exhibit, at any point in time, a population of values of the workload variables, the effects of a small change in these variables is a change in the requirements of a small proportion of the users—those for whom workload is shifted beyond a breakpoint. A large change effects a changed requirement for a large proportion of the users. The results of the study of maintenance improvement are to be applied servicewide to each appropriate aircraft Type/Model/Series (T/M/S) or Mission/Design/Series (M/D/S). Therefore, the impact on the aggregate support resource requirements and cost can be adequately estimated in a continuous fashion. The discrete models currently available for Support Investment elements may require modification to estimate cost in a continuous manner. This would represent a simplification and would be desirable for the vast reduction in data required to exercise the models.

In the area of estimating downtime impact, the question arises as to whether the complex interactions of various squadron and base operational and maintenance procedures, policies, requirements,and

events would be best reflected by a computer simulation. Such a simulation program exists—Comprehensive Aircraft Support Effectiveness Evaluation (CASEE)[11]. It is based on Naval operation and maintenance procedures for both carrier and land based aircraft.

At the present time, a statistical analysis of CASEE is planned to verify at the system level the confidence levels achieved in its recent validation at the 5-digit WUC level. Whereas it is advisable to apply CASEE, at the completion of this analysis, to the study of the downtime impact of maintenance improvement, there exists an interim approach.

The data required to utilize the interim approach (detailed in Section 2.4) is the NOR impact of each maintenance action. This information is currently provided by the Analytical Maintenance Program Computer Support (AMPCS) system. Specifically, it is available from AMPCS Report No. PTX 438P.

2.4 Readiness Considerations

Since the ultimate aim of this study will be to identify solutions to the causes of unnecessary maintenance and determine the most economical distribution of funds to these solutions, an optimization procedure will need to be utilized. Any procedure for minimizing cost is meaningful only in the presence of an effectiveness constraint—a measure of utility which must be considered together with cost for a balanced decision-making criterion. Operational Readiness is an appropriate effectiveness constraint for the maintenance improvement application.

System OR is a complex, non-additive combination of the downtime of all components. The combination is a non-linear

weighting which depends on component criticality to safety and mission performance as well as interacting stochastic processes. It is evident from this and the complexity of squadron operation and maintenance procedures for each WRA/LRU, in addition to their relation to intermediate and depot maintenance activities, that simulation is the only accurate modeling technique applicable to assessment of the OR impact of maintenance improvement. CASEE is the most advanced (i.e., realistic) squadron operation simulator available. The CASEE model simulates squadron operations and maintenance, as well as related activities which impact squadron performance (e.g., aircraft respotting procedures, intermediate maintenance turnaround times, and spares requirements). This model simulates maintenance at the 5-digit Work Unit Code (WUC) level (i.e., WRA level). Such input variables as Probability of No Repair Required, Maintenance Action Probabilities, Manpower Requirements, Skill Levels, Mean Time To Repair (MTTR), Probability of ATC 1-8, Probability of I-level discard (ATC 9), Number of Initially Outfitted Spares, Number of Ready For Issue (RFI) Spares, etc., are required for each WRA. It is this type of variable which would reflect the influence of improved maintenance on cost and readiness. In order to apply CASEE to the optimization problem, it would first be necessary to translate unnecessary maintenance causes and solutions into values for these inputs. For example, the influence of BIT on Probability of No Repair Required, Maintenance Action Probabilities, MTTR, etc., would be assessed through discussions with design engineers experienced with a given subsystem (e.g., fire control systems). The values of these

variables for a baseline aircraft (exhibiting reliability and maintainability characteristics currently being experienced in the fleet) would then be varied in accordance with these expected influences. A CASEE run would then provide outputs which reflect the impact of BIT on readiness. In addition to squadron readiness parameters, variables such as Maintenance Action Frequencies, Direct Maintenance Man-Hours, Supply Actions, ATC 1-8 actions, ATC 9 actions, etc. are provided as output at the WRA level. Such outputs would have to be translated, via cost relationships, into maintenance costs. Comparison of the calculated costs (both acquisition and O&S) with historical cost data for the baseline aircraft would provide an estimate of dollar savings or added expenditures resulting from the influences of a solution to an unnecessary maintenance problem. Readiness, as the effectiveness factor, would then enter the evaluation. This could be accomplished by factoring the differences in readiness between the improved system and the baseline system into a previously established cost-effectiveness relationship.

Another feasible approach to applying CASEE to the problem of assessing and optimizing the economics of maintenance improvement would be the utilization of a constant readiness strategy. Such an approach would involve extensive and complex searching algorithms to derive a collection of input value matrices which correspond to a given level of readiness. Tradeoffs could then be performed on the maintenance costs derived from WRA-level outputs and investment costs.

The purpose of the demonstration project will be to estimate the potential cost and downtime savings achievable via improvement

of the performance of maintenance. A simulation model such as CASEE will eventually be required, for the purposes of optimization, to accurately estimate the downtime (and possibly labor cost) sensitivity to MTTR, Maintenance Man-Hours (MMH) per Maintenance Action, and unnecessary maintenance action rates. However, for the present, it suffices to determine explicitly the downtime (and labor) impact of each and every unnecessary maintenance action. This may be accomplished by cross-referencing the NOR and MMH values provided by AMPCS Report Nos. PTX 438P and 438E, respectively to the Job Control Number (JCN) of each action identified via Report No. PTX 438D.

2.5 General Data Considerations

In seeking to determine which service, i.e., Navy or Air Force, to utilize for sample aircraft on which to assess the cost/downtime impact of unnecessary maintenance, data availability was the primary criterion.

2.5.1 Source Selection

The following paragraphs describe the rationale by which the most effective data source was selected and the types of ambiguities which would result from the use of even this data source. Air Force data from AFM 66-1 are available in hard copy with little user formatting capability. They are also stored on magnetic tape. The requisite data for simulation/cost analysis could therefore be converted to the appropriate form via a tape processing computer program.

Such a program would require development, which could be a time-consuming process. Another argument against the use of Air

Force data is the incompatibility of data on Air Force operations and maintenance, based on Air Force policies and procedures, with CASEE, A Navy oriented simulation program. The desirability of CASEE to satisfy the requirements of the maintenance improvement study for simulation was explained in Section 2.4.

CASEE utilizes Maintenance and Material Management (3-M) data and incorporates a 3-M magnetic tape pre-processor. Thus, to the extent to which simulation is utilized, a 3-M tape would be required for each aircraft T/M/S studied to provide a baseline point of departure for investigating the impact of maintenance improvement. Before applying CASEE, the contribution of each unnecessary maintenance problem to aggregate maintenance action rates and average MMH and Elapsed Maintenance Time (EMT) for each WRA must be estimated. This requirement is created by the aggregate/average level at which these parameters are input to CASEE.

A detailed individual maintenance action report generator with quick response and user selection, sorting, and formatting flexibility is needed in order to supply the requisite hard copy data. While 3-M data are available in hard copy and some potentially useful reports are published on a regular basis (monthly or quarterly), other valuable reports require a special request. Such a request could take a month or more to be filled and several such reports have been identified as relevant to this study. Direct access to 3-M report generation programs is not available to the analyst. 3-M tapes, if made available for local processing, would require development of a tape decoding and report generation program system.

The AMPCS system meets the above requirements[12]. AMPCS utilizes 3-M tape data as input, provides hard copy as output in many formats tailored further by the user to suit his needs. This facilitates the preliminary analysis without requiring the development of special-purpose tape processing programs. AMPCS reports are available via batch processing, accessible from a remote terminal. Turnaround time is 24 hours or less. Two AMPCS reports are of value for preventable maintenance action detection and labor cost assessment—Individual and Detailed Maintenance Action Reports (438D and 438E). Another useful capability of AMPCS is the availability of a report—Individual Downtime Maintenance Action Report (438P)—which provides the downtime (and degraded time) impact of each maintenance action as reported by squadron supervisory personnel, according to the Readiness Reporting System. This report meets perfectly the need to assess the downtime impact of recorded preventable maintenance actions. At such time as the CASEE simulation program is utilized and economic tradeoff analysis is to be conducted, the readiness impact of maintenance improvements will, however, be best obtainable from CASEE output.

2.5.2 Data Problems

The process of identifying preventable maintenance actions is, in general, an inferential process with an unavoidable, unquantifiable degree of error. This section delineates many of the potential pitfalls of the effort in terms of the ambiguities which remain after all the information contained in the hard data is extracted.

Errors in entry, coding, or keypunching MAF data are a significant data problem. Some occurrences are obvious, while others

are more subtle. Some errors, as discussed in Section 3.0 are beyond detection. An example of a data error which is both detectable and correctable is the case of two or more maintenance technicians servicing a piece of equipment and two or more filing a MAF. This is detected in the data reports as two action records identical except for slightly different JCN sequence numbers. A double check is to compare MMH to EMT. The ratio of MMH to EMT indicates the size of the crew performing the maintenance action.

In addition to data entry errors, coding and keypunching errors occur. Coding and keypunching are more susceptible to error because they are being performed by people unfamiliar with the meaning of the data with which they have been provided.

Another area of data unreliability is the practice of maintenance technicians deliberately masking their mistakes. In many cases, their failure to enter a HMC directly implicating maintenance or operations personnel can be overcome by the procedures described in Section 3.0. However, an example of deliberate masking which cannot be uncovered is the operator-griped equipment which is damaged by O-level technicians in the process of determining that it is a false alarm. The false alarm and the corrective action should be treated as two separate actions; but, due to human nature, they are probably not in most instances. The ATC probably entered on the MAF is that of the corrective action only. The same type of problem can be generated by I-level maintenance.

Another class of data problems is that of inferential error. For example, inference of Maintenance-Induced Defect or failure-to-correct a defect could always be mistaken. These could be occurrences

of failures due to endogenous causes, Operator-Induced Defect, or improper handling. What appears to be a failure-to-correct a defect could really be an instance of Maintenance-Induced Defect. Inference of trial-and-error diagnosis could be mistaken occurrences of unwarranted operator gripes, each resulting in an I-level action. The entry of a WDC Y could be taken as indication of an I or D-level Maintenance-Induced Defect or failure-to-correct a defect, a manufacturing defect, transportation/handling damage, or endogenous causes.

A set of potential inferential errors result from the fact that part serial numbers are not always available and entered. Also, while (in the case of ATC R events) the MAF has an entry for the serial numbers of the removed and replacement items, 3-M and AMPCS records display the number of the removed item only. This impedes the preventable maintenance action detection process as follows. A discrepancy is reported for an equipment. The equipment is removed and replaced with a like equipment cannibalized from another aircraft. The item initially removed is later found to result in a False Alarm at the I-level. The item cannibalized cannot be identified as the item being installed in the recipient aircraft due to lack of serial number recording. Therefore, this must be tracked by WUC/part number. WUC tracking is susceptible to a very small degree of error. If multiple cannibalization were performed on the same WUC in the same time frame, the MMH and EMT of the wrong one might be associated with the False Alarm.

Tracking of temporally clustered actions on same serial numbered equipment none of which involves ATC R can be performed

precisely by WUC. However, clusters of actions some of which result in I-level effort can be only partially identified. Using the serial number of the item removed at the O level for tracking, the time at which the item is installed on an aircraft (not necessarily the original aircraft) is not provided by the data. Therefore, if the criterion for clustering is a 2-day interval from installation to maintenance action, the closest proxy that can be applied is a 2 or 3-day interval between actions. If a 3-day interval is used and an item sits on the shelf in an RFI status for 4 days, the cluster will be screened out. For those few equipments which have elapsed operating time meters, this problem can be solved by using operating meter time for the clustering criterion.

One final data problem is the policy of the Navy's Readiness Reporting System of reporting an aircraft as being in a NOR condition only if it is down for more than the specified minimum time[13]. This results in an underestimation of the total loss of utility associated with unnecessary maintenance actions. On the other hand, the downtime considered significant by the Navy (as indicated by their definition) can be determined.

3.0 RESEARCH APPROACH

This section presents the analytical technique deemed feasible for the identification of obvious unnecessary maintenance actions and the detection of subtle occurrences of such actions. Each of the problem areas to be considered is treated in a separate subsection, as is a presentation of examples and a discussion of the desirability and feasibility of computerization of the technique.

3.1 False Alarms

A False Alarm can be generally defined as a maintenance action response to an alleged discrepancy wherein no legitimate fault can be found with the equipment in question. Such alleged discrepancies can be originated by the aircrew which believes it detects a malfunction or unacceptable performance in their equipment, or by the ground crew during their routine checks between flights. A maintenance action indicated by the reporting system to be a False Alarm can result from a failure of the maintenance personnel to correctly diagnose and repair a malfunction either by replacing the wrong component of a system (with no fault found at the next level of repair) or by incorrectly rejecting the alleged discrepancy as a no-defect complaint. This latter type of False Alarm requires one or more alleged discrepancies until a satisfactory repair is accomplished. Under the rules of reporting (e.g., Navy 3-M system), a False Alarm may involve some adjustments for "peaking" purposes, as long as the equipment was originally within specifications and the adjustment was not necessary to bring it within those specifications.

For purposes of these analyses, False Alarms may be considered in two categories; those recognized as a False Alarm (and so reported)

by the I-level maintenance personnel, and those resulting from O-level personnel's failure to reject an invalid gripe or correctly diagnose a malfunction, thereby replacing a functioning item, with subsequent False Alarm declared at the next maintenance level. The second type of False Alarm can be further compounded by the necessity of O-level personnel to obtain the replacement item by cannibalization of another aircraft. This requires two additional maintenance actions—one to remove the item from the cannibalized aircraft and one at a later date to replace the item.

The following discussion is directed toward the O-level False Alarm, the I-level False Alarm with O-level replacement from supply, and I-level False Alarm with O-level replacement via cannibalization. That portion of I-level False Alarms resulting from O-level failure to properly diagnose a problem is considered under Section 3.2, Failure-To-Repair.

3.1.1 Data Sources

False alarms in the Navy 3-M reporting system are uniquely identified by Action Taken Code A, defined as follows:

A. Item of Reparable Material or Weapons/Support System Discrepancy Checked—No Repair Required. This code is used for all discrepancies which are checked and found that either the reported deficiency cannot be duplicated, or the equipment is operating within allowable tolerances. Adjustments may be made under this code if the purpose of the adjustment is to peak or optimize performance. When adjustments are made, the malfunction code should reflect the reason for the adjustment (e.g., A-127, A-281, A-282, etc.). If the purpose of the adjustment is to bring the equipment within allowable tolerances, Action Taken Code C should be used (e.g., C-127, C-281, C-282, etc.)[9].

A False Alarm with no adjustments made is usually reported with How Malfunctioned Code 799, viz., A-799.

The special 3-M Report Number MSO 4790.A2551-01, "No Defect Item Analysis Summary," can provide summary A-799 data by command, aircraft, 4 and 5-digit WUC, and part number. However, ATC A with other HMCs (adjustments noted above) and the ability to differentiate between an isolated False Alarm and Failure-To-Repair is lost as is the association with cannibalization.

The AMPCS Individual Maintenance Action Record, Program Number 438D, and the Detailed Maintenance Action Report, Program Number 438E, can provide sufficient detail to determine the frequency, duration, and MMH of all maintenance actions with ATC A (regardless of HMC), for any selected organizations, aircraft, WUCs, and time period. These data are provided separately for the O and I levels. These runs provide a listing of individual maintenance actions identified by the JCN so that data from one report can be correlated with data from other reports. For example, 438D provides all necessary data except EMT and MMH; 438E provides O and I-level EMT and MMH, in addition to the other data, but omits O and I-level action dates provided in 438D. These two reports can be overlaid by JCN. In addition, Program Number 438P, Individual Downtime Maintenance Action Record, provides, for those maintenance actions resulting in a total NOR time greater than the specified minimum, the following time information[13]:

- Not Operationally Ready - Unscheduled Maintenance (NORMU)
- Not Operationally Ready Supply (NORS)
- Reduced Material Condition - Unscheduled Maintenance (RMCMU)

- Reduced Material Condition Supply (RMCS)
- Awaiting Maintenance

This run, too, can be overlaid onto the preceding data by JCN.

By selecting ATC A and the WUCs of interest, the volume of data obtained can be held to a reasonable limit. In order to identify False Alarms involving cannibalization, ATC T must also be selected, and all of the organizations (squadrons) serviced by a single IMA/AIMD must be selected. This is necessary to account for items cannibalized between squadron. Selection of an activity, i.e., carrier or land base, with only a few squadrons, will minimize the quantity of data.

3.1.2 Analytical Technique

O-level False Alarms are easily identified in the 438D run by scanning the O-level Action Taken Column for "A" entries. These can be grouped by HMC. Cross reference with 438E, using the JCN and aircraft Bureau Number can recover the associated MMH and EMT. Further cross reference with 438P shows whether or not there was a readiness impact, the magnitude, and the contributing factors. I-level False Alarms are identified in a similar manner, except that the I-level column is scanned for ATC A.

False Alarm frequencies at each level are determined by summing the "A" events, and the expended effort is found by summing the MMH for all events at both levels. Material costs cannot be recovered from any of these data. Readiness impact can be inferred by summing the correlated NORMU, NORS, and the Awaiting Maintenance times to obtain the NOR time. It should be noted, however, that this is not the total impact because only NOR times greater than the specified

minimum are recorded, and many maintenance actions which could be a cause of NOR time are masked by charging the NOR time to only one WUC when several occur simultaneously. Nevertheless, the above method does reflect the impact on readiness as reported.

The impact of False Alarms on the cannibalization rate can be inferred in the following manner. For each I-level event with ATC A, the O-level action date is noted, and the O-level events with ATC T (removed for cannibalization) are scanned for the same WUC/part number and action date within a day of the "A" event. When such a coincidence is found, it is assumed that the O-level "R" Action (remove and replace) associated with the I-level "A" action was completed via the cannibalization route. The data, as obtained through the 3-M system, are not explicit in this respect since they show the serial number of the removed item only (when entered on the MAF) and not the replacement item. To actually verify that the False Alarm involved a cannibalization action, the original MAF must be used since it notes the serial number of the installed item, when entered. While MAFs can be obtained from the squadrons of interest, who retain them for a period of six months, the risk of error associated with tracking via WUC instead of serial number is too small to incur the cost of tracking through the original MAFs.

Since cannibalization can occur between squadrons (although less likely than within a squadron), the data must include all the squadrons at a single location.

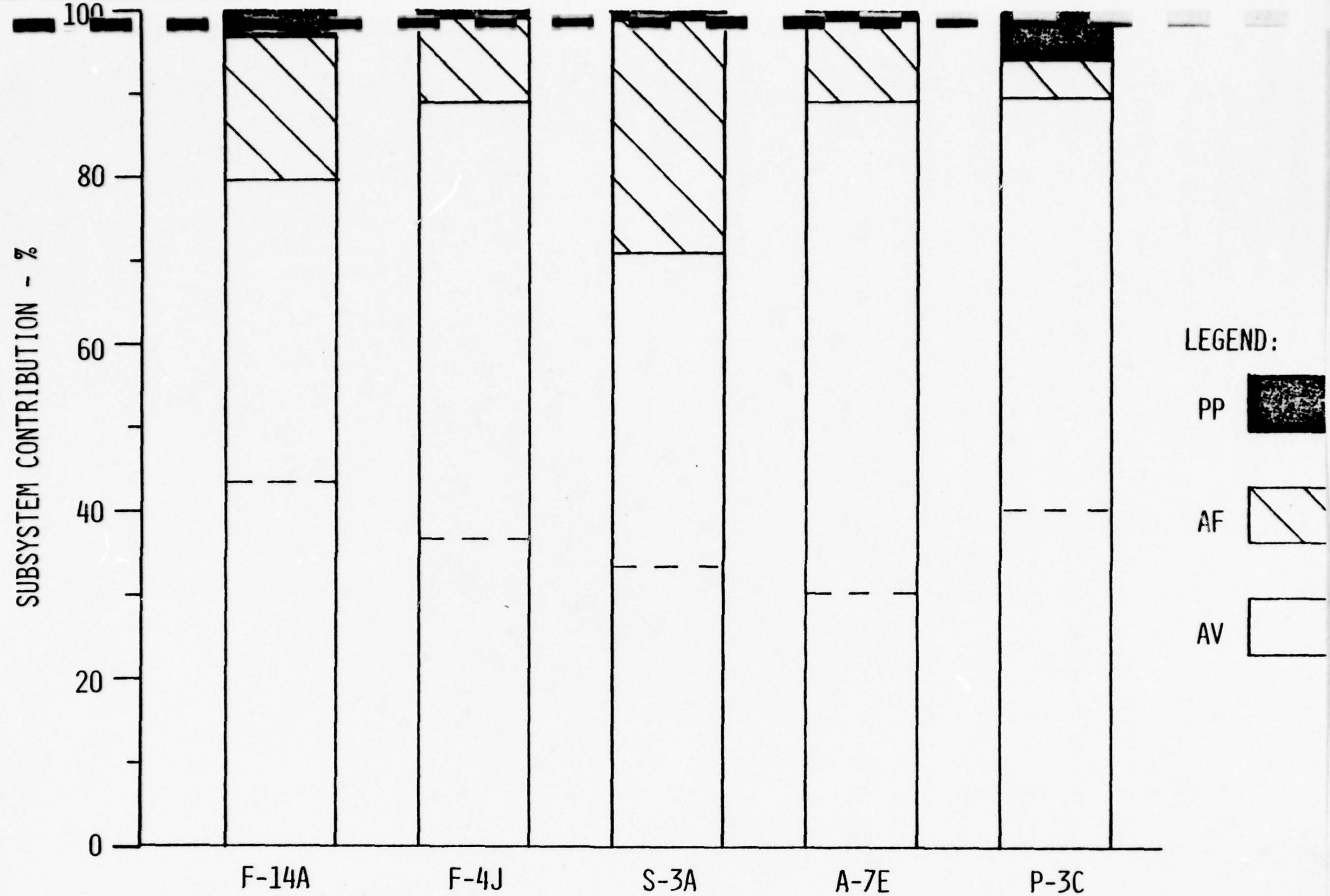
As noted previously, some False Alarms are created by the inability to correctly diagnose and fault isolate a malfunction.

The result is two or more False Alarms (at either level) occurring on the same Bureau Number, in close sequence, and on the same or functionally related WUC. This type of False Alarm, more correctly defined as an element of Failure-To-Repair, can more easily be identified by a different data analysis, discussed in Section 3.2. However, False Alarms identified as described above will include such diagnostic problems which can be subtracted from the total via the analysis of Section 3.2.

3.1.3 Subsystem Selection

In order to limit the scope of the Phase II effort to areas offering the most promise for economical maintenance improvement, a subsystem comparison was performed on False Alarm data. The sample data were obtained from the VAMOSC Maintenance Subsystem output for fiscal year 1976. The breakdown of I-level ATC A events by avionics, power plant, and airframe is displayed in Figure 2 as derived from Tables VI - X.

Figure 2 expands the cross-hatched area previously shown in Figure 1. This distribution among aircraft subsystems was determined from the data presented in Tables VI - X at the bottom of the page in the sixth column. As reflected in Figure 2, avionics contributes the vast majority of ATC A events at the I level, from 71.0 - 88.8% for the various aircraft depicted. Further, the highest-driving 2-digit WUC for each aircraft T/M/S, as indicated by the dashed line, contributes from 30.28 - 43.45% of the total ATC A events. The highest drivers are WUC 74 for the F-14A and F-4J, and WUC 73 for the S-3A, A-7E, and P-3C.



SOURCE: FY 76 VAMOSC-MS

Figure 2. Subsystem Contribution to False Alarms

TABLE VI. WUC BREAKDOWN OF FALSE ALARMS & CANNIBALIZATIONS - F-14A[14]

WUC	MA	T	A	$\frac{A_{WUC}}{MA}$ (%)	$\frac{A_{WUC}}{A_{AC}}$ (%)	$\frac{T_{WUC}}{T_{AC}}$ (%)
11	430	479	9	2.1	0.12	3.24
12	179	191	17	9.5	0.22	1.29
13	3428	763	762	22.2	9.81	5.15
14	764	563	88	11.5	1.13	3.80
22	-	-	-	-	-	-
23	1311	283	16	1.2	0.21	1.91
24	-	-	-	-	-	-
27	15	6	1	6.6	0.01	0.04
29	1630	1112	301	18.5	3.88	7.51
32	-	-	-	-	-	-
41	506	418	56	11.1	0.72	2.82
42	682	549	186	27.3	2.40	3.71
44	122	171	19	15.6	0.24	1.15
45	372	310	25	6.7	0.32	2.09
46	257	189	7	2.7	0.09	1.28
47	251	15	31	12.4	0.40	0.10
49	304	259	97	31.9	1.25	1.75
51	1186	645	233	19.6	3.00	4.36
52	-	-	-	-	-	-
54	-	-	-	-	-	-
56	2355	1683	695	29.5	8.95	11.37
57	659	478	287	43.6	3.70	3.23
58	1	0	0	0.0	0.0	0.0
61	-	-	-	-	-	-
62	-	-	-	-	-	-
63	770	471	140	18.2	1.80	3.18
64	133	68	30	22.6	0.39	0.46
65	450	128	115	25.6	1.48	0.86
66	49	1	5	10.2	0.06	0.01
67	184	79	52	28.3	0.67	0.53
69	1421	942	351	24.7	4.52	6.36
71	476	255	191	40.1	2.46	1.72
72	185	181	29	15.7	0.37	1.22
73	1320	482	305	23.1	3.93	3.26
74	7686	3286	3374	43.9	43.45	22.19
75	796	488	178	22.4	2.29	3.30
76	782	178	160	20.5	2.06	1.20
77	-	-	-	-	-	-
91	126	126	4	3.2	0.05	0.85
92	-	-	-	-	-	-
93	-	-	-	-	-	-
96	5	1	1	20.0	0.01	0.01
97	3	6	1	33.3	0.01	0.04
AC Total	28838	14806	7766	26.9		
AF	7168	3851	1300	18.1	16.7	26.0
PP	3226	1590	324	10.0	4.2	10.7
AV	18444	9365	6142	33.3	79.1	63.3

TABLE VII. WUC BREAKDOWN OF FALSE ALARMS & CANNIBALIZATIONS - F-4J[15]

WUC	MA	T	A	$\frac{A_{WUC}}{MA}$ (%)	$\frac{A_{WUC}}{A_{AC}}$ (%)	$\frac{T_{WUC}}{T_{AC}}$ (%)
11	307	180	6	2.0	0.05	1.42
12	276	166	21	7.6	0.18	1.31
13	11044	339	238	2.2	2.02	2.68
14	1718	570	178	10.4	1.51	4.50
22	-	-	-	-	-	-
23	5210	253	75	1.4	0.64	2.00
24	-	-	-	-	-	-
27	-	-	-	-	-	-
29	537	154	111	20.7	0.94	1.22
32	-	-	-	-	-	-
41	1019	330	46	4.5	0.39	2.61
42	1755	592	459	26.2	3.90	4.68
44	138	109	45	32.6	0.38	0.86
45	1124	406	140	12.5	1.19	3.21
46	795	202	54	6.8	0.46	1.60
47	588	38	59	10.0	0.50	0.30
49	25	31	0	0.0	0.0	0.24
51	2117	824	209	9.9	1.78	6.51
53	2	2	1	50.0	0.01	0.02
54	3	2	0	0.0	0.0	0.02
56	4694	1477	809	17.2	6.88	11.67
57	1550	457	289	18.6	2.46	3.61
59	1	0	0	0.0	0.0	0.0
61	11	0	0	0.0	0.0	0.0
62	-	-	-	-	-	-
63	1025	149	166	16.2	1.41	1.18
64	374	94	96	25.7	0.82	0.74
65	764	68	249	32.6	2.12	0.54
66	151	0	8	5.3	0.07	0.0
67	8587	1520	1558	18.1	13.24	12.01
69	3	1	0	0.0	0.0	0.01
71	690	148	189	27.4	1.61	1.17
72	2639	429	1115	42.3	9.48	3.39
73	2672	938	861	32.2	7.32	7.41
74	23240	2935	4340	18.7	36.88	23.18
75	1652	68	194	11.7	1.65	0.54
76	1198	77	231	19.3	1.96	0.61
77	79	4	3	3.8	0.03	0.03
91	255	62	13	5.1	0.11	0.49
92	1	0	1	100.0	0.01	0.0
93	233	13	1	0.4	0.01	0.10
96	14	0	0	0.0	0.0	0.0
97	9	23	1	11.1	0.01	0.18
AC Total	76500	12661	11767	15.4		
AF	18491	2859	1213	6.6	10.3	22.6
PP	6578	609	239	3.6	2.0	4.8
AV	51431	9193	10315	20.1	87.7	72.6

TABLE VIII. WUC BREAKDOWN OF FALSE ALARMS & CANNIBALIZATIONS - S-3A[16]

WUC	MA	T	A	$\frac{A_{WUC}}{MA}$ (%)	$\frac{A_{WUC}}{A_{AC}}$ (%)	$\frac{T_{WUC}}{T_{AC}}$ (%)
11	325	329	4	1.2	0.14	1.97
12	14	43	0	0.0	0.00	0.26
13	3591	1045	512	14.3	17.90	6.26
14	622	856	71	11.4	2.48	5.13
22	-	-	-	-	-	-
23	-	-	-	-	-	-
24	353	305	25	7.1	0.87	1.83
27	546	382	16	2.9	0.56	2.29
29	466	596	4	0.9	0.14	3.57
32	-	-	-	-	-	-
41	367	426	31	8.4	1.08	2.55
42	583	630	83	14.2	2.90	3.78
44	379	217	22	5.8	0.77	1.30
45	204	260	2	1.0	0.07	1.56
46	96	96	0	0.0	0.0	0.58
47	152	40	23	15.1	0.80	0.24
49	182	239	30	16.5	1.05	1.43
51	880	957	19	2.2	0.66	5.74
52	-	-	-	-	-	-
54	-	-	-	-	-	-
56	366	532	46	12.6	1.61	3.19
57	781	596	222	28.4	7.76	3.57
58	-	-	-	-	-	-
61	239	161	37	15.5	1.29	0.96
62	-	-	-	-	-	-
63	233	240	24	10.3	0.84	1.44
64	886	1053	166	18.7	5.80	6.31
65	298	149	75	25.2	2.62	0.89
66	34	0	0	0.0	0.0	0.0
67	55	32	23	41.8	0.80	0.19
69	60	42	10	16.7	0.35	0.25
71	804	632	230	28.6	8.04	3.79
72	1116	921	109	9.8	3.81	5.52
73	5881	4675	954	16.2	33.34	28.02
74	30	16	2	6.7	0.07	0.10
75	220	36	10	4.5	0.35	0.22
76	245	247	7	2.9	0.24	1.48
77	684	347	98	14.3	3.43	2.08
91	83	543	5	6.0	0.17	3.25
92	-	-	-	-	-	-
93	-	-	-	-	-	-
96	5	2	0	0.0	0.0	0.01
97	1	42	1	100.0	0.03	0.25
AC Total	20807	16687	2861	13.8		
AF	6533	4672	784	12.0	27.4	28.0
PP	1454	1379	45	3.1	1.6	8.3
AV	12820	10636	2032	15.9	71.0	63.7

TABLE IX. WUC BREAKDOWN OF FALSE ALARMS & CANNIBALIZATIONS - A-7E[17]

WUC	MA	T	A	$\frac{A_{WUC}}{MA}$ (%)	$\frac{A_{WUC}}{A_{AC}}$ (%)	$\frac{T_{WUC}}{T_{AC}}$ (%)
11	326	125	3	0.9	0.04	0.85
12	307	139	16	5.2	0.21	0.95
13	7078	789	128	1.8	1.67	5.37
14	1144	600	82	7.2	1.07	4.09
22	-	-	-	-	-	-
23	3089	359	34	1.1	0.44	2.45
24	-	-	-	-	-	-
27	-	-	-	-	-	-
29	908	416	67	7.4	0.87	2.83
32	-	-	-	-	-	-
41	998	357	133	13.3	1.73	2.43
42	1352	314	207	15.3	2.70	2.14
44	844	239	98	11.6	1.28	1.63
45	1938	335	24	1.2	0.31	2.28
46	807	145	61	7.6	0.80	0.99
47	449	27	55	12.2	0.72	0.18
49	44	24	7	15.9	0.09	0.16
51	3350	1557	261	7.8	3.40	10.60
52	-	-	-	-	-	-
54	-	-	-	-	-	-
56	70	53	1	1.4	0.01	0.36
57	2259	732	400	17.7	5.22	4.99
58	-	-	-	-	-	-
61	-	-	-	-	-	-
62	-	-	-	-	-	-
63	3174	943	615	19.4	8.02	6.42
64	71	40	18	25.4	0.23	0.27
65	797	212	176	22.1	2.29	1.44
66	104	1	4	3.8	0.05	0.01
67	81	26	22	27.2	0.29	0.18
69	-	-	-	-	-	-
71	3788	1139	800	21.1	10.43	7.76
72	3427	780	1379	40.2	17.98	5.31
73	12713	4233	2322	18.3	30.28	28.83
74	991	356	186	18.8	2.43	2.42
75	4415	318	300	6.8	3.91	2.17
76	1532	271	261	17.0	3.40	1.85
77	32	7	4	12.5	0.05	0.05
91	303	140	5	1.7	0.07	0.95
92	-	-	-	-	-	-
93	-	-	-	-	-	-
96	2	0	0	0.0	0.0	0.0
97	1	6	0	0.0	0.0	0.04
AC Total	56349	14683	7669	13.6		
AF	14777	3095	758	5.1	9.9	21.1
PP	4813	920	162	3.4	2.1	6.3
AV	36759	10668	6749	18.4	88.0	72.6

TABLE X. WUC BREAKDOWN OF FALSE ALARMS & CANNIBALIZATIONS - P-3C[18]

WUC	MA	T	A	$\frac{A_{WUC}}{MA}$ (%)	$\frac{A_{WUC}}{A_{AC}}$ (%)	$\frac{T_{WUC}}{T_{AC}}$ (%)
11	293	164	6	2.0	0.10	0.83
12	335	168	3	0.9	0.05	0.85
13	4576	248	44	1.0	0.74	1.26
14	220	132	22	10.0	0.37	0.67
22	1203	332	57	4.7	0.96	1.68
23	-	-	-	-	-	-
24	532	314	15	2.8	0.25	1.59
27	-	-	-	-	-	-
29	1864	605	194	10.4	3.25	3.07
32	1351	349	104	7.7	1.74	1.77
41	1106	640	58	5.2	0.97	3.25
42	1029	533	108	10.5	1.81	2.70
44	242	77	34	14.0	0.57	0.39
45	161	73	5	3.1	0.08	0.37
46	129	31	1	0.8	0.02	0.16
47	188	139	11	5.9	0.18	0.70
49	156	84	4	2.6	0.07	0.43
51	3055	1473	100	3.3	1.68	7.47
52	388	352	32	8.2	0.54	1.78
54	1	0	1	100.0	0.02	0.0
56	339	163	1	0.3	0.02	0.83
57	669	214	152	22.7	2.55	1.09
58	1	0	0	0.0	0.0	0.0
61	1213	790	206	17.0	3.45	4.01
62	911	410	165	18.1	2.77	2.08
63	1010	458	293	29.0	4.91	2.32
64	756	497	143	18.9	2.40	2.52
65	1182	519	272	23.0	4.56	2.63
66	33	3	1	3.0	0.02	0.02
67	783	362	148	18.9	2.48	1.84
69	1149	547	31	2.7	0.52	2.77
71	3584	1328	442	12.3	7.41	6.73
72	3379	1280	826	24.4	13.85	6.49
73	14870	7007	2400	16.1	40.23	35.53
74	304	55	35	11.5	0.59	0.28
75	249	16	14	5.6	0.23	0.08
76	349	239	1	0.3	0.02	1.21
77	208	36	34	16.3	0.57	0.18
91	91	82	3	3.3	0.05	0.42
92	-	-	-	-	-	-
93	-	-	-	-	-	-
96	0	1	0	0.0	0.0	0.01
97	-	-	-	-	-	-
AC Total	47909	19721	5966	12.5		
AF	8397	2341	296	3.5	5.0	11.9
PP	5079	1631	372	7.3	6.2	8.3
AV	34433	15749	5298	15.4	88.8	79.8

The data presented in Tables VI - X are organized as follows. The first column lists the WUCs in numerical sequence. The second column provides the number of I-level maintenance actions for each WUC for all aircraft of a given T/M/S for fiscal year 1976. At the bottom of this column are aircraft and subsystem totals. The third column provides O-level cannibalization actions for the respective WUCs. Total aircraft and subsystem cannibalization actions are provided at the bottom of this column. The fourth column provides the number of ATC A events at the I level by WUC, and aircraft and subsystem totals at the bottom of this column. The fifth column presents for each WUC the ratio of ATC A events (for that WUC) to Maintenance Actions (MA) (for that WUC). This is summarized for the aircraft and the respective subsystems. The sixth column provides a ratio of the ATC A events for a given WUC to the total ATC A events for the aircraft. At the bottom of this column the ATC A events are allocated by subsystem as previously described. The seventh column provides a ratio of ATC T events for a given WUC to the ATC T events of the aircraft. These are then allocated by subsystem at the bottom of this column.

It should be noted that WUCs 74 (F-14A and F-4J) and 73 (S-3A, A-7E and P-3C) in addition to being the highest contributors to False Alarms (ATC A), also account for the highest number of cannibalization actions at the O level. In addition, review of Tables VI - X reveals that over all aircraft, the highest non-avionic WUC contributing to both False Alarms and cannibalizations combined is WUC 13.

3.2 Failure-To-Repair

Failure-To-Repair is a contributor to unnecessary maintenance which involves repeated maintenance actions to correct a single deficiency. Such maintenance may result from one or more of the following causes:

- improper diagnosis
- improper fault isolation
- faulty workmanship, i.e., failure to correct a deficiency
- use of incorrect or faulty replacement parts/materials
- failure to properly reconnect/reassemble after effecting the basic corrective action
- failure to verify the repair.

Subsequent actions which are required to correct the original fault are recorded, and shown in the AMPCS data, as subsequent maintenance actions. Manpower, maintenance manuals, spares, etc. are therefore multiply taxed resources.

The successive maintenance actions required to isolate and correct a single fault is essentially a trial-and-error process with a discernible time interval between each pair of actions. Another type of Failure-To-Repair at the O level is the "shotgun" approach which involves the replacement of two or more items in the hope that one of them will be the cause of the discrepancy. While maintenance policy and practice should minimize the use of the "shotgun" technique, the exigencies of a particular repair and mission situation may compel the technician to adopt this approach. The result is that one of the replaced items will show up at the I level as a legitimate repair action, while the others will be False Alarms.

Failure-To-Repair at the O level affects only one aircraft Bureau Number, whereas Failure-To-Repair at the I level is likely to affect two or more aircraft. The reason is as follows. The O-level repair is directed at a problem residing within the aircraft, which will remain there until identified and successfully removed. At the I level, the problem is resident in the equipment removed from the aircraft, and remains in that equipment until successfully corrected. When the repair action is completed (successfully or not) the box is returned to supply, as RFI, and installed in an aircraft as needed. If the I-level repair were successful, the equipment would not be normally removed from its next recipient aircraft until it failed, or were subject to another removal requirement (e.g., cannibalization). If the I-level repair were not successful (failed to repair), and the equipment were returned to supply as RFI, it would manifest itself as a failure to the next recipient aircraft. Such a failure might show up immediately upon installation, or during the next flight after installation. Indeed, a subtle failure (e.g., intermittent in nature) might not be corrected by the I level, and could show up several flights after installation.

It should also be noted that when an equipment is returned to supply, it stays on the shelf for an indefinite period before it is required. Furthermore, the equipment may be installed in any aircraft of the same T/M/S in any squadron serviced by the IMA/AIMD. Thus, a Failure-To-Repair at the I level may be detected in any aircraft of the same T/M/S within the operational site, after some indefinite time duration. Upon the second occurrence, the equipment would be removed and the action recorded as would any other failure.

3.2.1 Data Sources

The data sources for Failure-To-Repair analyses are essentially the same as for the analysis of Section 3.1, with one exception. For the O-level failure-to-acknowledge and failure-to-correct a defect, the primary sorting of maintenance action records would be by Bureau Number, the secondary sorting to be by WUC, the tertiary sorting by date. Only ATCs A, B, C, R, Y, and Z, all WDCs, and all HMCs would be selected. Report No. 438D provides the time sequence information; 438E provides the MMH and EMT data; and NOR impact can be obtained from 438P. The sorting hierarchy required for failure-to-diagnose, since it involves functionally related WUCs, is Bureau Number followed by date.

I-level Failure-To-Repair analysis requires that an individual box or equipment be tracked from one aircraft to another. Therefore, each report would be required to include all Bureau Numbers of the same T/M/S at a given location. The sorting parameters, in order of decreasing precedence, are WUC, serial number, and date. The data recorded via the 3-M system include serial numbers of removed items only—not installed items. Therefore, in those cases in which the time interval between two successive removals of the same item serial number is too long to infer that the repair was not completed successfully, the inference will (at times mistakenly) be drawn that maintenance was performed properly. The existence of elapsed time meters on some equipments will reduce the likelihood of the incorrect inference being drawn. The only known source of installed serial number data (for the above ATCs) is the original handwritten MAF. Utilization of this source would be extremely tedious and time-consuming.

3.2.2 Analytical Technique

Analysis of Failure-To-Repair at the O level consists of identifying failures of O-level maintenance to verify the existence of a defect, to efficiently diagnose a malfunction, and take effective corrective action as indicated by ATCs B, C, or Z.

The case of failure-to-acknowledge a defect can be analyzed by scanning a single Bureau Number for a sequence of False Alarms on the same WUC, which are closely grouped by date, terminated by a corrective action. Since an O-level action date may differ from the JCN date, the appropriate technique is to look for clusters of actions from which the JCN date of each action is close to the O-level action date of the preceding action. Note that to avoid double-accounting, these False Alarms would be subtracted from those identified as described in Section 3.1.

The second problem area is the failure-to-diagnose, which includes the inefficient methods of trial-and-error and "shotgun." Trial-and-error can be detected by scanning the maintenance action records of a single Bureau Number for a sequence of actions on functionally related WUCs, closely grouped by date, such that all but one action is reported as a False Alarm at the I level, and the final action is corrective at the I level. Use of the "shotgun" method of diagnosis can be detected in a very similar manner. The only difference is that, while each replacement (and subsequent False Alarm or corrective action) is represented by a different JCN, all of the actions occur at virtually the same time—on the same day or two consecutive days. As in the case of failure-to-

acknowledge a defect, the False Alarms determined to be associated with failure-to-diagnose would be subtracted from those identified as described in Section 3.1. For both the "shotgun" and trial-and-error problems, prior knowledge of the functional relationships which impact the diagnostic procedure is essential.

The third problem area at the O level, failure-to-correct a defect, can be analyzed by scanning a single Bureau Number for a sequence of corrective actions at the O level on the same WUC, closely grouped by date. The above comment on JCN and action date comparisons applies here as well. Entry of the same HMC at each occurrence would lend weight to the inference of Failure-To-Repair. Note that use of the original MAF would be of value since descriptions of the discrepancy and corrective action are available there in narrative form. As mentioned previously, their utilization, unless in isolated instances only, would be a task whose magnitude renders it infeasible.

A weakness in the analysis logic described above, for failure-to-acknowledge and failure-to-correct a defect, is that an aircraft may not fly for extended periods of time, thus causing successive actions to appear to be independent. Meter times, when available, can be used as the clustering time parameter, thus circumventing this problem.

The technique for analysis of I-level Failure-To-Repair is basically that described for O-level failure-to-correct a defect. Since, in this case, an equipment can migrate from aircraft to aircraft of the same T/M/S at a given site, a single item serial number must be scanned for a sequence of maintenance actions which

are closely grouped by date, or meter times when available. In this case, grouping by date requires comparison of I-level action dates and the JCN dates of their subsequent actions.

3.3 Induced Defects

Induced defects are malfunctions or discrepancies which are humanly induced through handling or other contact such as physical, electrical, or thermal. For this analysis, such handling or contact is limited to that which occurs during, or in pursuance of operation, maintenance, or transportation. For example, an avionics box damaged because it was incorrectly inserted into its mount in the aircraft would be considered a Maintenance-Induced Defect. If the same box received the same damage as a result of an aircraft accident, it would not be so considered.

Induced defects at the O level can occur to an item during its removal, replacement (installation), or general handling between the aircraft and supply (by the maintenance personnel). It can occur as a result of dropping, banging into another object, using incorrect tools, over or under-torquing of fasteners, use of incorrect fasteners, misalignment during insertion, introduction of dirt or foreign materials, insertion with excessive force, mismating of connectors, shorting of electrical contacts, application of incorrect voltages, failure to provide proper cooling (e.g., operating an equipment while disconnected from its cooling air ducts), and the like.

Defects may be induced at the O level to equipments removed for other repair, equipments replaced to effect a repair, equipments removed and/or installed for other than immediate corrective

reasons (e.g., cannibalization, access to other equipment, scheduled removal/replacement, removal for troubleshooting, etc.), and equipments in the physical vicinity of removed items.

Some of the defects induced as described above can be detected simply by scanning corrective actions for induced-defect HMCs. This will very likely be an extremely small number of actions.

Defects may be similarly induced at the I level, but are restricted to the particular item being repaired. Additional induced defects at this level include such actions as overheating of parts through improper soldering techniques, mishandling of MOS semi-conductor devices, leaking or tearing of printed circuit board "wiring" or other wires, mishandling/damaging of delicate mother/daughter board connectors, improper extraction/insertion of printed circuit board modules, improper adjustment/setting/use of test equipment, failure to replace seals and gaskets, etc.

When a defect is induced in an item being removed for repair, or already under repair, it may be corrected as part of the original repair, and, therefore, not manifest itself as an additional maintenance action. However, when it occurs during non-corrective removal or installation, or to equipments removed and replaced for other than corrective reasons, or to physically adjacent equipments, or to equipments removed and re-installed for access purposes, another maintenance action will result. Even in the former case, if the induced damage is undetected or latent, it will manifest itself at another time (perhaps soon after the defect is induced) and, therefore, result in another maintenance action.

3.3.1 Data Sources

The data sources required for the induced defect analysis are the same as for the preceding analyses. For the O-level induced failures which result in additional maintenance actions (as noted in Section 3.3), maintenance action records sorted first by Bureau Number, next by WUC, then by date, are required. For those defects involving physically related WUCs, the requisite sorting priorities are Bureau Number followed by date. For those induced defects which are corrected as part of the original maintenance action, a listing of failed parts associated with each repair (as shown in Report No. 438E) is of value.

For I-level induced defects, data for all Bureau Numbers of the same T/M/S at a given location are required since an item repaired by the IMA/AIMD may be installed in any aircraft of that T/M/S at the same site. Reports sorted by WUC, serial number, and then date are therefore required as in the case of I-level Failure-To-Repair (See Section 3.2).

3.3.2 Analytical Technique

The simplest unreported induced defects to identify are those O-level incidents occurring to items removed and replaced for reasons other than corrective action. These result in corrective actions (O-level ATCs B, C, R, and/or Y) soon after non-corrective actions (ATCs P, Q, S, T, or U). A HMC indicative of mechanical/physical damage in conjunction with a corrective ATC reinforces the inference of induced damage. This tracking is performed by item serial number because some non-corrective actions result in re-installation in another aircraft.

Additional similarly induced defects can be identified by searching for corrective actions, as above, on physically related WUCs soon after any type of action on the related item. In addition, multiple corrective actions occurring simultaneously on physically related WUCs is suggestive of Maintenance-Induced Defects (all but one) if a HMC indicating operationally induced damage is not reported. Prior knowledge of the physical relationships is essential. Here again, mechanical/physical damage indicative HMCs reinforce the inference, though they are not conclusive.

O-level defects induced in an item being removed for repair, and I-level induced defects are much more difficult to identify. Two categories of such incidents must be considered. In the first case, the damage is corrected at the same time as the original discrepancy and only one maintenance action results. The only indication of such an event discernible from the data is in the listing of failed parts. When two or more parts are replaced which appear independent in their failure modes, and one of the HMCs is indicative of damage, while the other(s) appear to indicate causes of an endogenous nature, it may be inferred that the defect of the damaged part was induced. An example is a box removed for an internal defect, whose failed parts include a transistor (shorted, open, changed value, etc.) and a rear external connector that is broken or cracked. The two items and their failure modes indicate independence, and the logical conclusion is that the connector was broken as a result of removal or setting the box on the deck, with the protruding connector downward. Damage which is corrected by labor only and does not involve replacement

piece parts, (e.g., a broken wire/connection which is repaired by soldering only, or by replacing wire from bulk) is not reported in the data and is therefore not recoverable. In such cases, a conscientious maintenance technician might describe all of his repair effort on the MAF, but this would require an analysis of each and every MAF. This analysis requires detailed parts drawings, schematics, wiring diagrams, pictorial and exploded views, parts lists, maintenance instructions, as well as an intimate knowledge of the aircraft and the equipment. Every corrective maintenance action must be analyzed. In order to limit the magnitude of the effort, the study could be restricted to items known to be vulnerable to such induced defects. Indeed, the magnitude of the effort as compared to the minimal number of induced defects detectable in this manner argues against further investigating this problem area.

The second category includes those induced defects which are not detected and corrected during the maintenance action, or which may be latent. These will show up at a later time and in any aircraft of the same T/M/S at the same location. The manifestation is the same as for the I-level Failure-To-Repair and is identified by using the same analysis methods. The differences between the two are subtle, and would require the detailed analysis, noted above, of the data for all the actions in the sequence. While, in the absence of such analysis, some Maintenance-Induced Defects may be mistaken for Failure-To-Repair incidents, the error would be one of classification only.

Operator-Induced Defects, unless specifically identified by HMC 437, will most likely show up as damage type HMCs to external

components of the equipment (e.g., switches, knobs, pushbuttons, handles, etc.) which are exposed to the operator. If the repair is for this item only, it can be concluded that it was operator-induced; if the item were shown in conjunction with an internal repair, then it can be inferred (but not conclusively) that it was maintenance-induced.

3.4 Problem Tracking Examples

This section addresses the application of the analysis logic of paragraphs 3.1 to 3.3 to actual and assumed data. Table XI reproduces some of the pertinent data from a 438D output on the F-14A aircraft. The data were selected from a one-year accumulation of maintenance actions on two Bureau Numbers (158629 and 158634). In several instances, as noted, additional data were assumed for illustrative purposes.

3.4.1 Example A

This is an actual example of improper reporting, rather than improper maintenance. Two maintenance actions are shown which are identical in every respect except for the sequence number of the JCN. At first glance it would appear that unscheduled maintenance done on a fuselage component at the O level had to be repeated immediately. However, upon examination of the 438E run, it was determined from the EMT and the MMH that two technicians performed the maintenance. It was therefore concluded that each man completed a separate MAF, rather than a single one as should have been done. The impact in this case is inflation of frequency and manpower reporting. Such data errors occur frequently, but they can be detected and accounted for during the analysis of specific problems areas.

TABLE XI. PROBLEM TRACKING EXAMPLES

EXAMPLE	WORK UNIT CODE	PART NUMBER	SERIAL NO	JCN DATE	SEQ	ML=1 ACTN DATE	ML=2 ACTN DATE	W D	T M	ACTION TAKEN O	ACTION TAKEN I	MAL CODES O	MAL CODES I
A	1151500			5234	888	5241	0000	J	B	B	0	105	000
	1151500			5234	889	5241	0000	J	B	B	0	105	000
B	5152A00	FCR553033	106	6163	730	6168	6168	O	B	S	1	800	070
	4616100			6163	778	6166		H	B	B	0	190	000
C	1211900	MBEU1939GRU5	9596	6022	672	6022		O	B	T		799	
	1211900			6022	673	6034	0000	O	B	C	0	780	000
D	74A5300	481541161	DXP39	6049	739	6049		O	B	T		799	
	74A5300	481541-161	DXP39	6049	740	6049		O	B	U		799	
	74A5300	481541-161	DXP39	6049	815	6050	6050	H	B	R	C	C03	135
	74A5300	481541-161	DXP39	6051	820	6051	6051	H	B	R	C	C03	135
E	71D1300	3951171	0720	6090	689	6090	6092	H	B	R	C	070	070
	71D1200	3951901	0649	6090	690	6091	6092	H	B	R	A	242	027
	71D1100	3951921	0264	6090	691	6103	6092	H	B	R	A	294	799
F	734H100	680100-16X	EHL047	6095	839	6095		O	B	T		799	
	734H100	68D100-19	CHX062	6095	840	6096		O	B	U		799	
	734H100	680100-19	CXH062	6096	611	6104		O	B	R		801	
	734H100	680100-16X	GAQ034	6104	719	6104	6105	H	B	R	1	C38	374
	734H100	680100-16X	EHL046	6095	838	6095		H	B	R	A	242	799

SOURCE: AMPCS-438D, F-14A, BuNo. 158,629 and 158,634, FY-76, indicated by

3.4.2 Example B

This is an actual example of damage induced to a physically related item while repairing a legitimate malfunction. WUC 5152A00 is an internal cell tank unit which was removed by O-level personnel (ATC S, HMC 800) to repair WUC 4616100, a bladder cell, which was cracked (ATC B, HMC 190). The internal cell tank unit shows a depot level repair required as a result of ATC 1 (at I level) because it was broken (HMC 070), two days after the bladder cell was repaired at the O level. It is therefore assumed that the cell tank unit was broken in the process of removing or reinstalling it in the bladder cell. In this case, the problem was compounded by the fact that the I level was not authorized to repair the unit and, therefore, had to send it back to the depot. (Note: If the cell unit had a legitimate malfunction, it would have been reported as ATC R at the O level with a HMC of 070).

3.4.3 Example C

This is an actual example of damage induced to a unit which was removed for cannibalization purposes. An ejection seat installation component, WUC 1211900, was removed on day 022 (ATC T, HMC 799). It must be assumed that it would not have been used for this purpose were it not in acceptable condition. The same day (before it could be installed on the recipient aircraft) another MAF was issued because the unit was Bent, Buckled, etc. (HMC 780). The actual repair effort was accomplished twelve days later by O-level maintenance.

3.4.4 Example D

This is an example of two problems occurring in sequence to one item. the first is an actual example of damage induced via a cannibalization process, and the second is an assumed example of Failure-To-Repair at the O level. A Data Display Unit, WUC 74A5300, serial number DXP39, was removed and replaced the same day (049) for cannibalization purposes (ATCs T and U). The same day (049), a discrepancy was reported and the next day (050), it was removed and replaced at the O level and repaired at the I level (ATC C, HMC 135, Binding, Stuck, Jammed, etc.).

In the second (assumed) example, the following day (051), the repaired unit (same serial number, DXP39) was removed from another aircraft and repaired at the I level again, for exactly the same reasons. The immediate repetition of the discrepancy with the same HMCs indicates that the original I-level repair was ineffective (Failure-To-Repair) and had to be repeated.

3.4.5 Example E

This is an actual example of the "shotgun" approach used because of inadequate diagnostic and fault isolation capability. Three components of an AN/ARA 63 Receiving Decoding Group, a radio receiver (WUC 71D1100), a pulse decoder (WUC 71D1200), and a receiver control (WUC 71D1300) were reported discrepant and removed on the same day. The O level diagnosed the receiver control as Broken (HMC 070); the pulse decoder as Failed to Operate, Specific Cause Unknown (HMC 242); and the radio receiver as Failing Self-Test (HMC 294). I level agreed with the "Broken" diagnosis for the receiver control, but found no real discrepancies with the other

units, although they made minor adjustments to the pulse decoder.

Using the 438E data, the two non-defective units took 2.0 and 3.6 hours to replace at the O level, and 1.0 and 0.5 hours to check out at the I level. This accounted for a total of 13 MMH at both levels.

3.4.6 Example F

This example includes Failure-To-Repair at the O level, Maintenance-Induced Defect at the O level (or, perhaps, Failure-To-Repair at a higher level), and a False Alarm compounded by cannibalization necessitated by the replacement requirement. The first two problems within the overall example are derived from actual data, while the third is an assumed problem. An Inertial Measuring Unit (IMU), WUC 734H100, was removed for cannibalization (day 095) and replaced with another like unit the following day (ATCs T and U). The part number of the replacement unit is very similar to that of the removed unit, but different in its suffix (-19 instead of -16x). The same day (096), it was replaced and scheduled to be removed for modification. There are several explanations for this. The wrong part (an unmodified one denoted by the suffix -19) may have been inadvertently installed, but not immediately removed because of lack of modified units (suffix -16x), or it might have been installed intentionally with full awareness that it would have to be removed for modification. One week later (104), the unmodified unit (same serial number) was removed for modification (ATC R, HMC 801) and replaced with a modified unit (suffix -16x). If this action were inadvertent, it would be an example of Failure-To-Repair by virtue of using the wrong part.

If intentional, it is a type of Failure-To-Repair (satisfactorily), but one into which maintenance was forced, perhaps by a supply shortage. In either case, an additional maintenance action was incurred, involving two men for 0.5 hours (438E shows EMT = 0.5 hour and O-level MMH = 1.0 hour). (Note: examination of the original MAFs could possibly shed some light on this situation).

The same day the IMU was replaced by a correct version (day 104), the replacement unit failed and had to be replaced (O-level ATC R, I-level ATC 1). This could be either a Maintenance-Induced Defect caused by installation or Failure-To-Repair at a higher level. Since the I level has no capability to repair these units, and since it appears that they were in a state of modification, it is also possible that the depot (or contractor) induced the failure during modification, or it was damaged during shipping. A random failure is also possible, but discounted as unlikely in this example.

The third problem, an assumed occurrence, traces the installation of the original cannibalized IMU, by action date (095), to another aircraft whose IMU was removed for an alleged discrepancy (ATC R, HMC 242, Failed to Operate, Specific Reason Unknown) and found to be a False Alarm by I-level maintenance (ATC A, HMC 799).

3.5 Computerization

The analytical techniques formulated in Sections 3.1 through 3.4 demonstrate that it is indeed possible to identify unnecessary maintenance actions of several types. Many of these types of maintenance action, however, require tedious and time-consuming detective effort to uncover. In addition, there are three data reports of value all of which must be cross referenced for maintenance

action identification, labor cost estimation, and readiness impact assessment. Moreover, there are many maintenance actions in a year for one aircraft, let alone a squadron. This quantity is compounded by the fact that multiple squadrons of the same T/M/S aircraft at one site may cannibalize each other's aircraft and it is difficult to locate a site for each chosen T/M/S at which only one squadron of aircraft is based. Furthermore, the study of maintenance improvement should be conducted on several sample aircraft subsystems, not just one. Physical and functional relationships among equipment create additional dimensions of complexity in the detective process. In light of all the above considerations, it seems that the feasibility of the study of maintenance improvement could be greatly enhanced by automation of the analytical techniques described above.

To automate the techniques without duplicating software contained in the AMPCS system, for extracting, sorting, and formatting relevant data from 3-M tapes, the useful AMPCS output reports must be obtained on tape storage. It has been determined that such output tapes are created and can be made available for the purposes of the study of maintenance improvement.

To demonstrate the feasibility of computerization, a set of problem identification logic diagrams was developed. The initial diagram, Figure 3, depicts the hierarchical breakdown of unnecessary maintenance action problem areas. The number in parentheses in Figure 3 near each of the major blocks is keyed to the appropriate section of this report. The flow of logic required to implement the analytical technique is presented in Figures 4 - 6 for analysis of False Alarm, Failure-To-Repair, and Induced Defect, respectively.

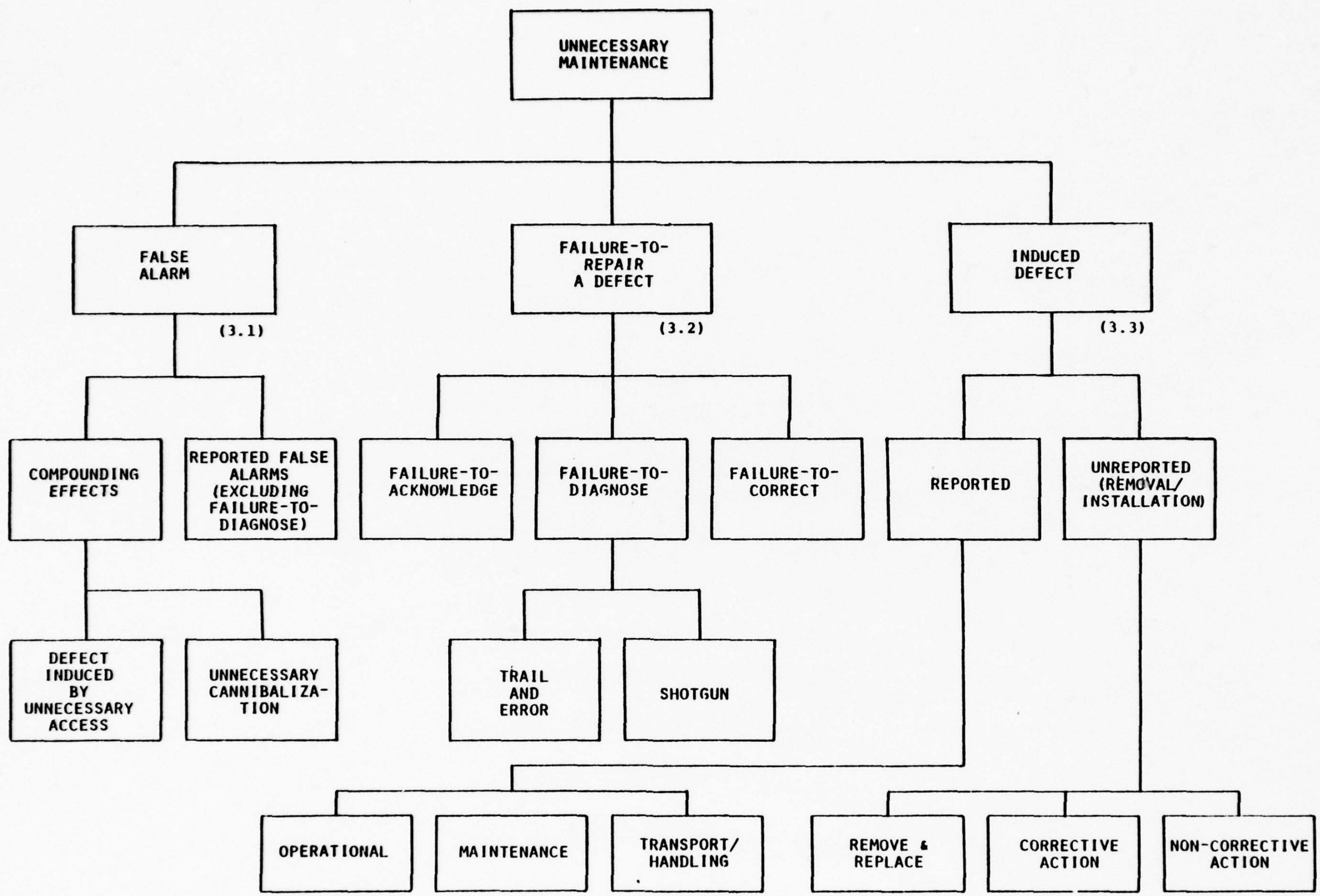


FIGURE 3. HIERARCHICAL BREAKDOWN OF UNNECESSARY MAINTENANCE

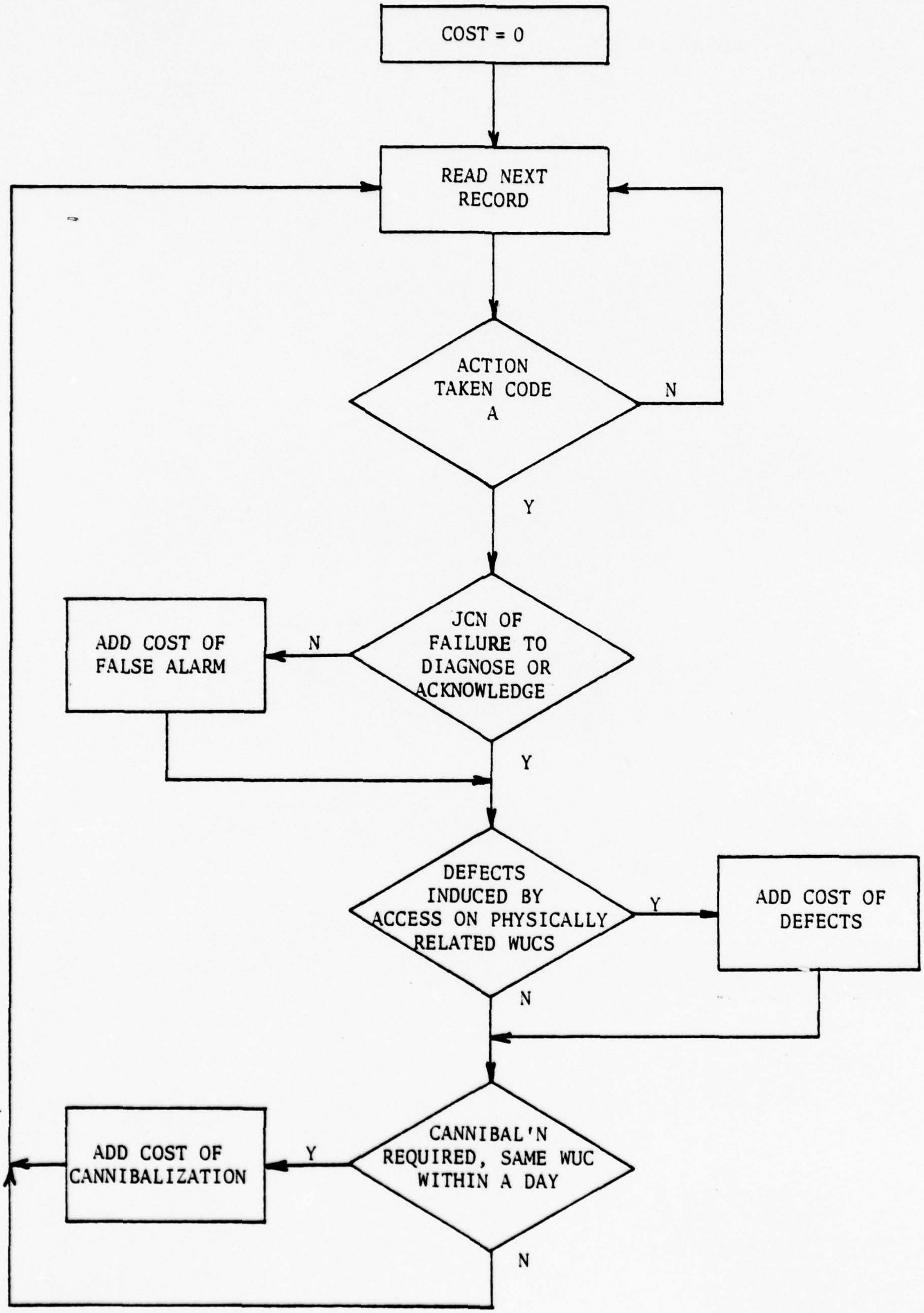


Figure 4. Analytical Logic Flow (False Alarm)

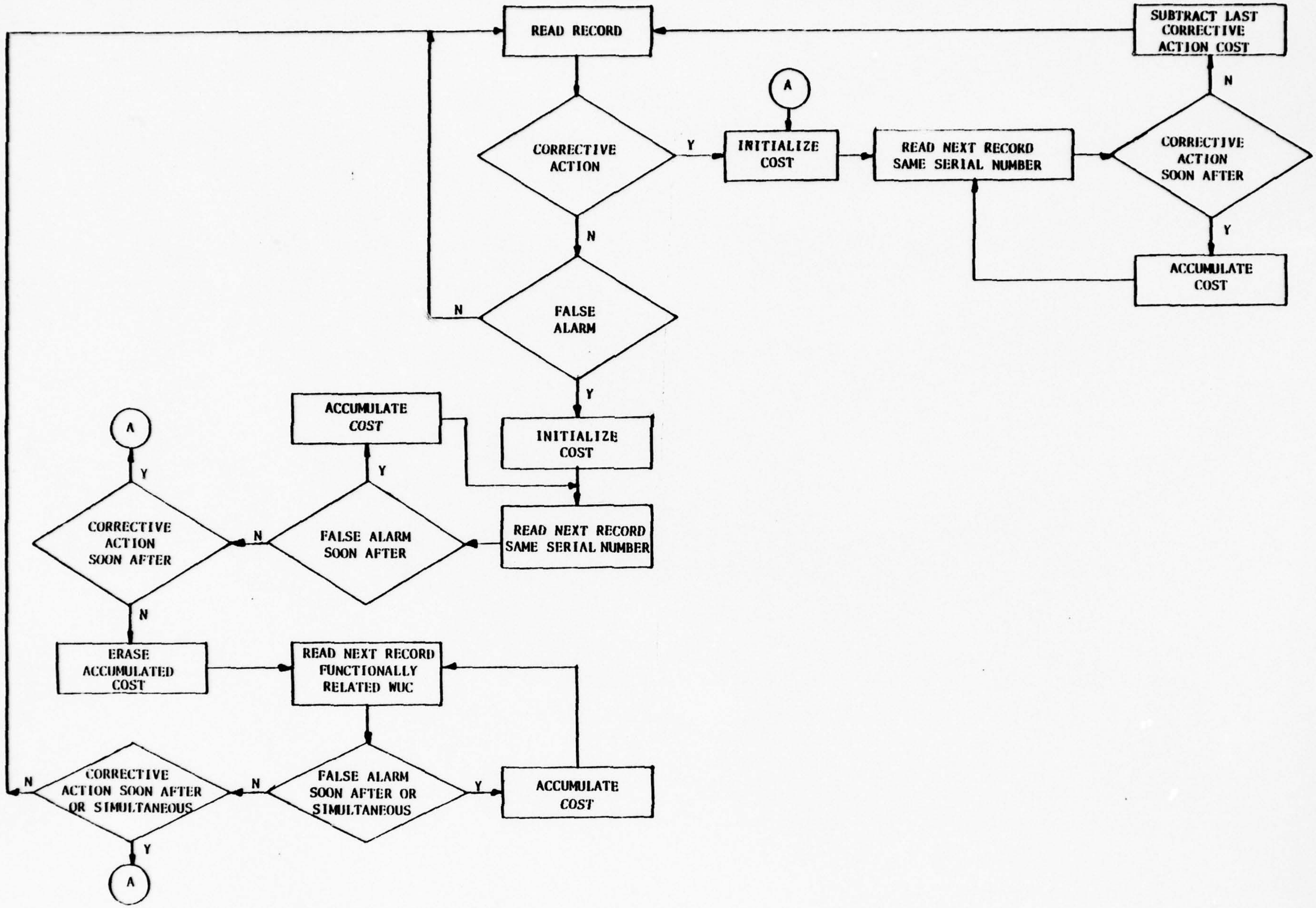


FIGURE 5. ANALYTICAL LOGIC FLOW (FAILURE-TO-REPAIR)

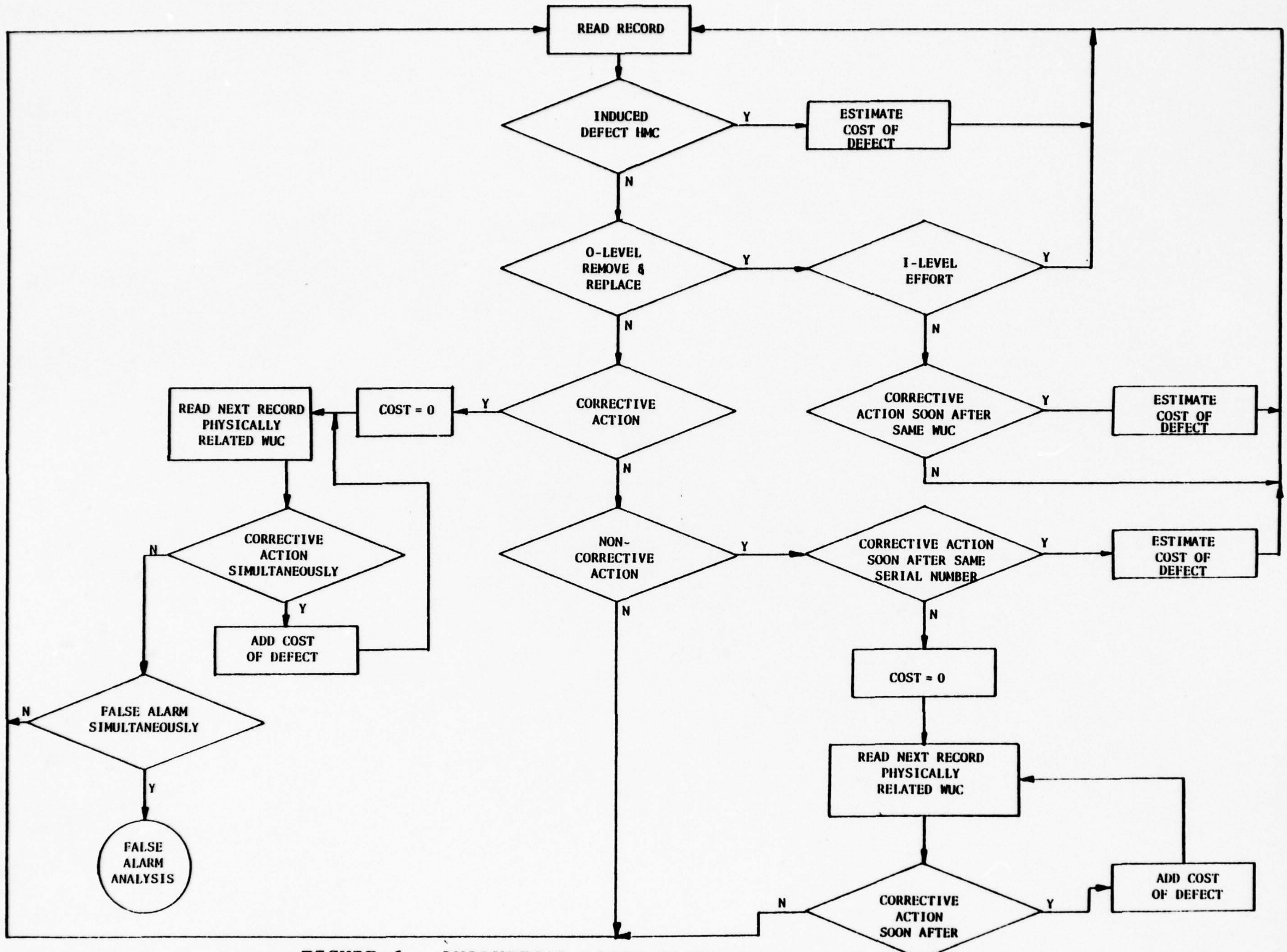


FIGURE 6. ANALYTICAL LOGIC FLOW (INDUCED DEFECTS)

4.0 CONCLUSIONS & RECOMMENDATIONS

This section summarizes the results of the Phase I feasibility study and recommendations for the conduct of a Phase II demonstration study. These results include the selection of problem areas and subsystems to be studied, and the formulation of an analytical approach to assessing the cost saving potential of improving maintenance with respect to the selected problem areas.

4.1 Areas for Phase II Study

Considering feasibility and potential benefit as criteria, the types of unnecessary maintenance action selected for the Phase II demonstration study are:

- False Alarm
  - Organizational Level
  - Intermediate Level
  - Depot Level
- Failure-To-Repair
  - Failure-To-Acknowledge
  - Failure-To-Diagnose
  - Failure-To-Correct
- Induced Defects
  - Operational
  - Maintenance
    - Organizational Level
    - Intermediate Level
  - Transportation/Handling

The lack of depot level maintenance action data amenable to single-thread tracking prevents the accurate detection of False

Alarms, Failure-To-Repair, or Shipping/Maintenance-Induced Defects at the depot. While occurrences of the latter two problems can be identified by a When Discovered Code Y, only the magnitude of the depot False Alarm problem can be estimated. Depot False Alarm estimation will require on-site interviews and/or inspection of depot records to provide an approximate proportion of items processed which are determined to be non-defective.

Two areas within Maintenance-Induced Defect are, though not necessarily intractable, difficult to pursue and not certain to be identifiable. One is the area of defects induced during repair of the same item and repaired at the same time; the other is the area of defects induced during diagnosis of a False Alarm and repaired at that time. These two types of improper maintenance are easy for an unconscientious maintenance technician to mask by the manner in which he fills out the MAF.

4.2 Subsystems Selected for Phase II Analysis

As mentioned previously, the AMPCS system provides the most useful data for the Phase II demonstration study. This fact leads to the conclusion that the study should utilize a sample of Naval aircraft. The only data utilized during the Phase I feasibility study were those already available at the start of Phase I. These data were utilized to select those WUCs with the greatest potential for cost savings resulting from maintenance improvement—in particular, reduction of ATC A and T events, i.e., False Alarms and associated cannibalization, failure-to-diagnose, and failure-to-acknowledge defects.

The aircraft T/M/S chosen for Phase II are highly utilized,

high-performance aircraft with a considerable avionics complement:

- F-14A
- F-4J
- S-3A

The F-14A is the Navy's most advanced operational fighter aircraft and is complemented by the F-4J as its presently operational predecessor fighter aircraft. The S-3A has a large quantity of BIT, which lends itself to the study of BIT performance relative to False Alarm and Failure-To-Repair analyses.

The highest-driving 2-digit WUC on the fighters is WUC 74 and, on the S-3A, is WUC 73. To provide a broader sample of subsystems to be studied, the highest-driving non-avionic 2-digit WUC can also be selected for study in Phase II. As mentioned earlier (under paragraph 3.1.3), WUC 13 is that WUC on the S-3A.

4.3 Feasibility of Analytical Approach

As demonstrated in Sections 3.1 through 3.4, there is a feasible approach to the identification of unnecessary maintenance actions. The approach is subject to a small amount of error, but much of this error is in classification of the type of action. For instance, some ATC A events are the result of unwarranted gripes on equipment which is not in need of repair. Others are the result of inefficient troubleshooting techniques. While it is possible to misclassify some failures-to-diagnose as False Alarms and vice-versa, all ATC A events result from one of these problems and, thus, the sum of the estimates of these two problem areas would be an accurate estimate of the combined problem area. The same comments apply to failures-to-correct a defect and

Maintenance-Induced Defect involving multiple corrective maintenance actions.

As demonstrated in Section 3.5, the logic of the technical approach, while time-consuming if performed manually, can be automated. Automation would require software development and built-in data checks to identify and account for data errors where possible. Computerization, however, is the most feasible method by which to implement the analytical technique.

4.4 Recommendations

Considering the potential cost and downtime savings achievable by reducing the incidence of unnecessary maintenance, and considering the feasibility of implementing the technical approach as described in Section 3.0, it is recommended that the study of the economics of maintenance improvement proceed with Phase II. Further, it is recommended that, during Phase II, the analytical technique described in Section 3.0 be implemented on a small-scale basis for demonstration purposes. In particular, the following aircraft T/M/S and 2-digit WUCs are recommended as subjects of this investigation:

- F-14A, WUC 74
- F-4J, WUC 74
- S-3A, WUCs 13 & 73

The specific tasks recommended for the accomplishment of Phase II and the corresponding milestone schedule are as presented in Appendix C.

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ACTION TAKEN CODES

CODE DESCRIPTION

A **BENCHED CHECKED AND REPAIRED**
BENCH CHECK AND REPAIR OF ANY ONE ITEM IS ACCOMPLISHED AT THE SAME TIME. (ALSO SEE CODE F).

B **BENCH CHECKED - SERVICEABLE**
(NO REPAIR REQUIRED)-ITEM IS BENCH CHECKED AND NO REPAIR IS REQUIRED.

C **BENCH CHECKED - REPAIR DEFERRED**
BENCH CHECK IS ACCOMPLISHED AND REPAIR ACTION IS DEFERRED. (SEE CODE F)

D **BENCH CHECKED - TRANSFERRED TO ANOTHER BASE OR UNIT**
ITEM IS BENCH CHECKED AT A FORWARD OPERATING BASE, DISPERSED OPERATING BASE OR ENROUTE BASE AND IS FOUND UNSERVICEABLE AND TRANSFERRED TO A MAIN OPERATING BASE OR HOME BASE FOR REPAIR. THIS CODE WILL NOT BE USED FOR ITEMS RETURNED TO A DEPOT FOR OVERHAUL. THIS CODE WILL ALSO BE USED WHEN PME OR OTHER EQUIPMENT IS SENT TO ANOTHER BASE OR UNIT FOR BENCH CHECK, CALIBRATION, OR REPAIR AND IS TO BE RETURNED, AND FOR ITEMS FORWARDED TO CONTRACTORS ON BASE LEVEL CONTRACTS.

1 **BENCH CHECKED - NRTS (NOT REPAIRABLE THIS STATION)-REPAIR NOT AUTHORIZED**
SHOP IS NOT AUTHORIZED TO ACCOMPLISH THE REPAIR. THIS CODE SHALL ONLY BE USED WHEN THE REPAIR REQUIRED TO RETURN AN ITEM TO SERVICEABLE STATUS IS SPECIFICALLY PROHIBITED BY CURRENT TECHNICAL DIRECTIVES. THIS CODE SHALL NOT BE USED DUE TO LACK OF AUTHORITY FOR EQUIPMENT, TOOLS, FACILITIES, SKILLS, PARTS OR TECHNICAL DATA.

ACTION TAKEN CODES
(CONTINUED)

2 **BENCH CHECKED - NRTS - LACK OF EQUIPMENT, TOOLS OR FACILITIES**
REPAIR IS AUTHORIZED BUT CANNOT BE ACCOMPLISHED DUE TO LACK OF EQUIPMENT, TOOLS OR FACILITIES. THIS CODE SHALL BE USED WITHOUT REGARD AS TO WHETHER THE EQUIPMENT, TOOLS OR FACILITIES ARE AUTHORIZED OR UNAUTHORIZED.

3 **BENCH CHECKED - NRTS - LACK OF TECHNICAL SKILLS**
REPAIR CANNOT BE ACCOMPLISHED DUE TO LACK OF TECHNICALLY QUALIFIED PEOPLE.

4 **BENCH CHECKED - NRTS - LACK OF PARTS**
PARTS ARE NOT AVAILABLE TO ACCOMPLISH REPAIR.

5 **BENCH CHECKED - NRTS - SHOP BACKLOG**
REPAIR CANNOT BE ACCOMPLISHED DUE TO EXCESSIVE SHOP BACKLOG.

6 **BENCH CHECKED - NRTS - LACK OF TECHNICAL DATA**
REPAIR CANNOT BE ACCOMPLISHED DUE TO LACK OF MAINTENANCE MANUALS, DRAWINGS, ETC., WHICH DESCRIBE DETAILED REPAIR PROCEDURES AND REQUIREMENTS.

7 **BENCH CHECKED - NRTS - EXCESS TO BASE REQUIREMENTS**
REPAIR WILL NOT BE SCHEDULED FOR SHOP REPAIR DUE TO ITEM BEING EXCESS TO BASE REQUIREMENTS.

8 **BENCH CHECKED - RETURN TO DEPOT**
RETURNED TO DEPOT BY DIRECTION OF SYSTEM MANAGER (SM) OR ITEM MANAGER (IM). USE ONLY WHEN ITEMS THAT ARE AUTHORIZED FOR BASE LEVEL REPAIR ARE DIRECTED TO BE RETURNED TO DEPOT FACILITIES BY SPECIFIC

ACTION TAKEN CODES
8 **BENCH CHECKED - RETURN TO DEPOT**
(CONTINUED)

WRITTEN OR VERBAL COMMUNICATION FROM THE IM OR SM, OR WHEN ITEMS ARE TO BE RETURNED TO DEPOT FACILITIES FOR MODIFICATION IN ACCORDANCE WITH A TIME COMPLIANCE TECHNICAL ORDER (TCTO), OR AS UR EXHIBITS.

9 **BENCH CHECKED - CONDEMNED**
ITEM CANNOT BE REPAIRED AND IS TO BE PROCESSED FOR CONDEMNATION, RECLAMATION OR SALVAGE. THIS CODE WILL ALSO BE USED WHEN A 'CONDEMNED' CONDITION IS DISCOVERED DURING FIELD MAINTENANCE DISASSEMBLY OR REPAIR.

E **INITIAL INSTALLATION**
FOR INSTALLATION ACTIONS THAT ARE NOT RELATED TO A PREVIOUS REMOVAL ACTION SUCH AS INSTALLATION OF ADDITIONAL EQUIPMENT OR INSTALLATION OF AN ITEM TO REMEDY A SHIP-SHORT CONDITION. THIS CODE WILL BE USED ONLY FOR EQUIPMENT MANAGED UNDER THE ADVANCED CONFIGURATION MANAGEMENT SYSTEM. REFERENCE TO'S 00-20-2-2, 00-20-2-5 AND 00-20-2-7 MUST BE USED WITH HOW MAL CODE 799

F **REPAIR**
NOT TO BE USED TO CODE 'ON EQUIPMENT' WORK IF ANOTHER CODE WILL APPLY. WHEN IT IS USED IN A SHOP ENVIRONMENT THIS CODE WILL DENOTE REPAIR AS A SEPERATE UNIT OF WORK AFTER A BENCH CHECK. SHOP REPAIR INCLUDES THE TOTAL REPAIR MANHOURS AND INCLUDES CLEANING, DISASSEMBLY INSPECTION, ADJUSTMENT, REASSEMBLY AND LUBRICATION OF MINOR COMPONENTS INCIDENT TO THE REPAIR WHEN THESE SERVICES ARE PERFORMED BY THE SAME WORK CENTER. FOR PRECISION MEASUREMENT EQUIPMENT, THIS CODE WILL BE USED ONLY WHEN CALIBRATION OF THE REPAIRED ITEM IS REQUIRED (SEE CODE G).

ACTION TAKEN CODES
(CONTINUED)

G **REPAIR AND OR REPLACEMENT OF MINOR PARTS, HARDWARE AND SOFTGOODS**
(SEALS, GASKETS, ELECTRICAL CONNECTORS, FITTINGS, TUBING, HOSE, WIRING, FASTENERS, VIBRATION ISOLATORS, BRACKETS, ETC.)
WORK UNIT CODES DO NOT COVER MOST NON-REPAIRABLE ITEMS. THEREFORE, WHEN ITEMS SUCH AS THOSE IDENTIFIED ABOVE ARE REPAIRED OR REPLACED, THIS ACTION TAKEN CODE WILL BE USED. WHEN THIS ACTION TAKEN CODE IS USED, THE WORK UNIT CODE WILL IDENTIFY THE ASSEMBLY BEING SERVICED OR MOST DIRECTLY RELATED TO PARTS BEING REPAIRED OR REPLACED. FOR EXAMPLE, IF AN ELECTRICAL CONNECTOR WAS REPAIRED AND WAS ATTACHED TO A RADIO TRANSMITTER, THE WORK UNIT CODE FOR THE TRANSMITTER WOULD BE USED WITH THIS ACTION TAKEN CODE. FOR PRECISION MEASUREMENT EQUIPMENT THIS CODE WILL BE USED FOR REPAIRS THAT DO NOT REQUIRE CALIBRATION OF THE REPAIRED ITEM. (SEE CODE F).

H **EQUIPMENT CHECKED - NO REPAIR REQUIRED (FOR 'ON EQUIPMENT' WORK ONLY)**
ALL DISCREPANCIES WHICH ARE CHECKED AND FOUND TO REQUIRE NO FURTHER MAINTENANCE ACTION. THIS CODE WILL BE USED ONLY IF IT IS DEFINITELY DETERMINED THAT A REPORTED DEFICIENCY DOES NOT EXIST OR CANNOT BE DUPLICATED. MUST BE USED WITH HOW MAL CODE 799 OR 812.

J **CALIBRATED - NO ADJUSTMENT REQUIRED**
USE THIS CODE WHEN AN ITEM IS CALIBRATED AND FOUND SERVICEABLE WITHOUT NEED FOR ADJUSTMENT, OR IS FOUND TO BE IN TOLERANCE BUT IS ADJUSTED MERELY TO PEAK OR MAXIMIZE THE READING. IF THE ITEM

ACTION TAKEN CODES
J CALIBRATED - NO ADJUSTMENT REQUIRED
(CONTINUED)

REQUIRES ADJUSTMENT TO ACTUALLY MEET CALIBRATION STANDARDS OR TO BRING IN TOLERANCE, USE CODE K.

K **CALIBRATED - ADJUSTMENT REQUIRED**
ITEM MUST BE ADJUSTED TO BRING IT IN TOLERANCE OR MEET CALIBRATION STANDARDS. IF THE ITEM WAS REPAIRED OR NEEDS REPAIR IN ADDITION TO CALIBRATION AND ADJUSTMENT, USE CODE F.

L **ADJUST**
INCLUDES ADJUSTMENTS NECESSARY FOR SAFETY AND PROPER FUNCTIONING OF EQUIPMENT SUCH AS ADJUST,BLEED,BALANCE,RIG,FIT,REROUTE,SEAT/RESEAT, POSITION/REPOSITION,PROGRAM /REPROGRAM,OR ACTUATING RESET BUTTON, SWITCH OR CIRCUIT BREAKER.FOR USE WHEN A DISCREPANCY OR CONDITION IS CORRECTED BY THESE TYPES OF ACTIONS.IF THE IDENTIFIED COMPONENT OR ASSEMBLY ALSO REQUIRES REPLACEMENT OF BITS AND PIECES AS WELL AS ADJUSTMENT,ENTER THE APPROPRIATE REPAIR ACTION TAKEN CODE

INSTEAD OF L.

M **DISASSEMBLE**
DISASSEMBLY ACTION WHEN THE COMPLETE MAINTENACE JOB IS BROKEN INTO PARTS AND REPORTED AS SUCH. DO NOT USE FOR ON-EQUIPMENT WORK.

N **ASSEMBLE**
ASSEMBLY ACTION WHEN THE COMPLETE MAINTENANCE JOB IS BROKEN INTO PARTS AND REPORTED AS SUCH. DO NOT USE FOR ON-EQUIPMENT WORK.

P **REMOVED**
ITEM IS REMOVED AND ONLY THE REMOVAL IS TO BE ACCOUNTED FOR. IN THIS INSTANCE DELAYED OR AD-

ACTION TAKEN CODES
P REMOVED
(CONTINUED)

DITIONAL ACTIONS WILL BE ACCOUNTED FOR SEPERATELY. (ALSO SEE CODES Q, R, S, T AND U). DO NOT USE FOR OFF-EQUIPMENT WORK.

Q **INSTALLED**
ITEM IS INSTALLED AND ONLY THE INSTALLATION ACTION IS TO BE ACCOUNTED FOR. (ALSO SEE CODES E, P, R, S, T AND U) DO NOT USE FOR OFF-EQUIPMENT WORK.

R **REMOVE AND REPLACE**
ITEM IS REMOVED AND ANOTHER LIKE ITEM IS INSTALLED. (ALSO SEE CODES T AND U). DO NOT USE FOR OFF-EQUIPMENT WORK.

S **REMOVE AND REINSTALL**

ITEM IS REMOVED AND THE SAME ITEM REINSTALLED. (ALSO SEE CODES T AND U). DO NOT USE FOR OFF-EQUIPMENT WORK. MUST BE USED WITH HOW MAL CODE 800, 804 OR 805.

T **REMOVE FOR CANNIBALIZATION**
A COMPONENT IS CANNIBALIZED. THE WORK UNIT CODE WILL IDENTIFY THE COMPONENT BEING CANNIBALIZED. DO NOT USE THIS CODE FOR OFF-EQUIPMENT WORK. MUST BE USED WITH HOW MAL CODE 799.

U **REPLACED AFTER CANNIBALIZATION**
THIS CODE WILL BE ENTERED WHEN A COMPONENT IS REPLACED AFTER CANNIBALIZATION. DO NOT USE THIS CODE FOR OFF-EQUIPMENT WORK. MUST BE USED WITH HOW MAL CODE 799.

V **CLEAN**
CLEANING IS ACCOMPLISHED TO CORRECT DISCREPANCY AND/OR WHEN CLEANING IS NOT ACCOUNTED FOR AS PART OF A REPAIR ACTION SUCH AS CODE F. INCLUDES WASHING, ACID BATH, BUFFING, SAND BLASTING.

ACTION TAKEN CODES

V **CLEAN**
(CONTINUED)

DEGREASING, DECONTAMINATION, ETC. CLEANING AND WASHING OF COMPLETE ITEMS SUCH AS GROUND EQUIPMENT VEHICLES, MISSILES OR AIRPLANES SHOULD BE RECORDED BY UTILIZING SUPPORT GENERAL CODES.

X **TEST - INSPECTION - SERVICE**
ITEM IS TESTED OR INSPECTED OR SERVICED (OTHER THAN BENCH CHECK) AND NO REPAIR IS REQUIRED. THIS CODE DOES NOT INCLUDE SERVICING OR INSPECTION CHARGEABLE TO SUPPORT GENERAL WORK UNIT CODES.

Y **TROUBLESHOOT**
TIME EXPENDED IN LOCATING A DISCREPANCY IS GREAT ENOUGH TO WARRANT SEPERATING THE TROUBLE-SHOOT TIME FROM THE REPAIR TIME. USE OF THIS CODE NECESSITATES COMPLETION OF TWO SEPERATE LINE ENTRIES, OR TWO SEPERATE FORMS. ONE FOR THE TROUBLESHOOT PHASE AND ONE FOR THE REPAIR PHASE. WHEN RECORDING THE TROUBLESHOOT TIME SEPERATE FROM THE REPAIR TIME. THE TOTAL TIME TAKEN TO ISOLATE THE PRIMARY CAUSE OF THE DISCREPANCY SHOULD BE RECORDED UTILIZING THE WORK UNIT CODE OF THE DEFECTIVE SUBSYSTEM OR SYSTEM. DO NOT USE FOR OFF EQUIPMENT WORK.

Z **CORROSION REPAIR**
INCLUDES CLEANING, TREATING, PRIMING AND PAINTING OF CORRODED ITEMS. THIS CODE SHOULD ALWAYS BE USED WHEN ACTUALLY TREATING CORRO-DED ITEMS, EITHER ON EQUIPMENT OR IN THE SHOP. THE WORK UNIT CODE SHOULD IDENTIFY THE ITEM THAT IS CORRODED. USE SUPPORT GENERAL CODE FOR PAINTING OR CORROSION PREVENT-IVE TREATMENT PRIOR TO AN ITEM BE-COMING CORRODED.

ACTION TAKEN CODES

CODE **DESCRIPTION**

ACTION TAKEN CODES 1 THROUGH 9 ARE RESTRICTED TO THOSE REPAIRABLE ITEMS OF MATERIAL WHICH HAVE BEEN ADMINISTRATIVELY OR TECHNICALLY SCREENED AND FOUND TO BE NOT-REPAIRABLE AT AN AIMD (BY DESIGNATED INTERMEDIATE LEVEL PERSONNEL AUTHORIZED TO MAKE THESE DETERMINATIONS). IN KEEPING WITH THE PHILOSOPHY OF REPAIR AT THE LOWEST PRACTICABLE LEVEL, THE AIMD IS AUTHORIZED TO PERFORM ANY AND ALL FUNCTIONS FOR WHICH IT HAS OR CAN BE GRANTED AUTHORITY AND THE CAPABILITY TO PERFORM AND MEET PERFORMANCE SPECIFICATIONS.

1. BCM - REPAIR NOT AUTHORIZED. THIS CODE IS USED WHEN THE ACTIVITY CONCERNED IS NOT SPECIFICALLY AUTHORIZED AND CANNOT BE AUTHORIZED REPAIR CAPABILITY FOR AN ITEM.

2. BCM - LACK OF AUTHORIZED EQUIPMENT, TOOLS, OR FACILITIES. THIS CODE IS USED WHEN REPAIR IS AUTHORIZED BUT CANNOT BE PERFORMED BECAUSE OF A LACK OF AUTHORIZED EQUIPMENT, TOOLS, OR FACILITIES.

3. BCM - LACK OF TECHNICAL SKILLS. THIS CODE IS ENTERED WHEN REPAIR EXCEEDS SKILL CAPABILITY OF ASSIGNED PERSONNEL. (SEE ALSO 5.)

4. BCM - LACK OF PARTS. THIS CODE IS ENTERED WHEN PARTS ARE NOT AVAILABLE LOCALLY OR HAVE NOT BEEN REPORTED AS AVAILABLE AND SHIPPED TO THE REQUESTING ACTIVITY TO ACCOMPLISH REPAIR WITHIN TIME LIMITS ESTABLISHED BY EXISTING DIRECTIVES.

5. BCM - SHOP BACKLOG. THIS CODE IS ENTERED WHENEVER EXCESSIVE SHOP BACKLOG PRECLUDES REPAIR WITHIN LIMITS SPECIFIED BY CURRENT DIRECTIVES.

6. BCM - LACK OF TECHNICAL DATA. THIS CODE IS ENTERED WHEN REPAIR CANNOT BE ACCOMPLISHED DUE TO LACK OF MAINTENANCE MANUALS, DRAWINGS, ETC., WHICH DESCRIBE DETAILED REPAIR PROCEDURES AND REQUIREMENTS.

7. BCM - EXCESS TO SHIP/ACTIVITY REQUIREMENTS. THIS CODE IS ENTERED WHEN ITEMS OF MATERIAL WILL NOT BE SCHEDULED FOR SHOP REPAIR, DUE TO BEING IN EXCESS OF LOCAL REQUIREMENTS. THIS DETERMINATION CAN ONLY BE MADE BY THE LOCAL SUPPLY OFFICER AND/OR HIGHER AUTHORITY.

8. BCM - BUDGETARY LIMITATIONS. THIS CODE IS USED WHEN THERE ARE INSUFFICIENT FUNDS TO EXPEND OR THERE ARE LIMITED FUNDS AVAILABLE WHICH ARE RESERVED FOR REPAIR OF ITEMS OF MATERIAL CONSIDERED TO BE OF A MORE URGENT PRIORITY.

9. CONDEMNED. THIS CODE IS ENTERED WHEN THE ITEM CANNOT BE ECONOMICALLY REPAIRED AND IS TO BE PROCESSED FOR CONDEMNATION, RECLAMATION, OR SALVAGE.

ALL OFF CODES LISTED BELOW MAY BE USED FOR BOTH ON OR EQUIPMENT WORK UNLESS OTHERWISE NOTED.

A. ITEM OF REPAIRABLE MATERIAL OR WEAPONS/SUPPORT SYSTEM DISCREPANCY CHECKED = NO REPAIRS REQUIRED. THIS CODE WILL BE USED FOR ALL DISCREPANCIES CHECKED AND FOUND THAT EITHER THE REPORTED DEFICIENCY CANNOT BE DUPLICATED, OR THE EQUIPMENT IS OPERATING WITHIN ALLOWABLE TOLERANCES. ADJUSTMENTS MAY BE MADE UNDER THIS CODE IF THE REASON IS TO PEAK OR OPTIMIZE PERFORMANCE. WHEN ADJUSTMENTS ARE ACCOMPLISHED, THE MALFUNCTION CODE SHOULD REFLECT THE REASON FOR ADJUSTMENT E.G. A-127, A-281, A-282, ETC. IF THE PURPOSE OF THE ADJUSTMENT IS TO BRING THE EQUIPMENT WITHIN ALLOWABLE TOLERANCES, ACTION TAKEN CODE C SHOULD BE USED E.G. C-127, C-281, C-282, ETC.

B. REPAIR AND/OR REPLACEMENT OF ATTACHING UNITS, SEALS, GASKETS, PACKING, ELECTRICAL CONNECTIONS, WIRING, CIRCUITS, TUBING, HOSE, CONNECTORS, FITTINGS, ETC., THAT ARE NOT AN INTEGRAL PART OF WORK UNIT CODED ITEMS OR COMPONENTS AS PURCHASED FROM THE MANUFACTURER AND HELD IN THE SUPPLY SYSTEM IN AN RFI STATUS. THESE UNITS ARE NOT IDENTIFIED BY WORK UNIT CODES AND ARE NORMALLY A CONNECTING LINK IN A WEAPON/SUPPORT SYSTEM BETWEEN TWO OR MORE COMPONENTS THAT DO HAVE WORK UNIT CODES ASSIGNED. THEREFORE, WHEN ITEMS OF THIS NATURE ARE REPAIRED OR REPLACED, THIS ACTION TAKEN CODE IS USED. IN CASE OF DOUBT REGARDING WHICH COMPONENT TO IDENTIFY IN THE WUC BLOCK, THE WUC OF THE COMPONENT SERVICED WILL BE USED.
EXAMPLE: IF A CANNON PLUG TO THE LANDING GEAR ACTUATOR DOES NOT HAVE A WUC, THE CODE FOR THE LANDING GEAR ACTUATOR WILL BE ENTERED.

C. REPAIR. THIS CODE IS ENTERED WHEN A REPAIRABLE ITEM OF MATERIAL WHICH IS IDENTIFIED BY A WUC IS REPAIRED. REPAIR INCLUDES CLEANING, DISASSEMBLY, INSPECTION, REASSEMBLY, LUBRICATION AND REPLACEMENT OF INTEGRAL PARTS; ADJUSTMENTS ARE INCLUDED IN THIS DEFINITION IF THE PURPOSE OF THE ADJUSTMENT IS TO BRING THE EQUIPMENT WITHIN ALLOWABLE TOLERANCES. (SEE ALSO ACTION TAKEN CODE A.) THIS CODE ALSO APPLIES TO THE CORRECTION OF A DISCREPANCY ON A WEAPON/SUPPORT SYSTEM WHEN APPROPRIATE.

D. WORK STOPPAGE - POST/PRE-DEPLOYMENT. THIS CODE IS ENTERED TO CLOSE OUT MAF COPY NO. 3 WHEN COMPONENT REPAIR IS INTERRUPTED UPON COMPLETION OF A DEPLOYMENT AND REPAIR IS TO BE PERFORMED AT ANOTHER FACILITY.
(SEE NOTE AT END OF CODES)

E. LOCAL MANUFACTURE: THIS CODE IS USED TO DOCUMENT THE LOCAL MANUFACTURE OF MISSILE TARGET REPAIR PARTS, SPECIAL EQUIPMENT, AND PECULIAR SUPPORT EQUIPMENT. (FOR USE IN MISSILE AND MISSILE TARGET ACTIVITIES ONLY.)
(SEE NOTE AT END OF CODES)

J. CALIBRATED - NO ADJUSTMENT REQUIRED. THIS CODE IS USED WHEN AN ITEM IS CALIBRATED AND FOUND SERVICEABLE WITHOUT NEED FOR ADJUSTMENT. IF THE ITEM REQUIRES ADJUSTMENT TO MEET CALIBRATION STANDARDS, USE CODE K. (THIS CODE APPLIES TO PME ONLY.)
(SEE NOTE AT END OF CODES)

K. CALIBRATED - ADJUSTMENT REQUIRED. THIS CODE IS USED WHEN AN ITEM MUST BE ADJUSTED TO MEET CALIBRATION STANDARDS. IF THE ITEM NEEDS REPAIR IN ADDITION TO CALIBRATION AND ADJUSTMENT, USE ANOTHER CODE INDICATING THE PROPER MAINTENANCE ACTION. (THIS CODE APPLIES TO PME ONLY.)
(SEE NOTE AT END OF CODES)

L. WORK STOPPAGE - AWAITING PARTS. THIS CODE IS ENTERED WHEN A MAINTENANCE ACTION MUST BE STOPPED OR DELAYED WHILE AWAITING PARTS WHICH ARE NOT AVAILABLE LOCALLY, AND THE COMPONENT GOES INTO AN AWAITING PARTS, STATUS. (USE OF THIS CODE IN BLOCK 40 OF THE MAF IS OPTIONAL, AT THE DIRECTION OF THE COGNIZANT TYPE COMMANDER.)

M. WORK STOPPAGE - OTHER. THIS CODE IS ENTERED WHEN A MAINTENANCE ACTION MUST BE STOPPED, DELAYED, OR DEFERRED, AND IS BEING CLOSED OUT FOR DATA PROCESSING. THESE CASES INCLUDE (1) MAINTENANCE REASONS, SUCH AS TO RELEASE PERSONNEL, TOOLS, EQUIPMENT OR FACILITIES FOR JOBS WITH A MORE URGENT PRIORITY OR TO EFFECT REPAIR AT A MORE PRACTICABLE TIME, OR (2) IN THE CASE OF AN AIRCRAFT ACCIDENT, TO CLOSE OUT AN ASSIGNED MAINTENANCE ACTION.

N. WORK IN PROGRESS. THIS CODE IS ENTERED WHEN IT BECOMES NECESSARY FOR A WORK CENTER TO CLOSE OUT A MAF AT THE END OF THE REPORTING PERIOD. (USE OF THIS CODE IS OPTIONAL, AT THE DIRECTION OF THE COGNIZANT TYPE COMMANDER.)

CODES P THROUGH S ARE USED FOR ON EQUIPMENT MAINTENANCE ONLY.

P. REMOVED. THIS CODE IS ENTERED WHEN AN ITEM OF MATERIAL IS REMOVED AND ONLY THE REMOVAL IS TO BE ACCOUNTED FOR. IN THIS INSTANCE DELAYED OR ADDITIONAL ACTIONS ARE ACCOUNTED FOR SEPARATELY. (SEE ALSO R, S AND T.)

Q. INSTALLED. THIS CODE IS ENTERED WHEN AN ITEM IS INSTALLED AND ONLY THE INSTALLATION ACTION IS TO BE ACCOUNTED FOR. (SEE ALSO U.)

R. REMOVE AND REPLACE. THIS CODE IS ENTERED WHEN AN ITEM OF MATERIAL IS REMOVED DUE TO A SUSPECTED MALFUNCTION AND THE SAME OR A LIKE ITEM REINSTALLED. (SEE ALSO CODES T & U AND THE NOTE AT THE END OF THE CODES.)

S. REMOVE AND REINSTALL. THIS CODE IS ENTERED WHEN AN ITEM OF MATERIAL IS REMOVED TO FACILITATE OTHER MAINTENANCE AND THE SAME ITEM IS REINSTALLED . ACTION TAKEN CODE S IS LIMITED TO MALFUNCTION CODES 800, 801 AND 804. (SEE ALSO CODES T AND U.)

T. REMOVED FOR CANNIBALIZATION. THIS CODE IS USED WHEN AN ITEM OF MATERIAL IS CANNIBALIZED.

U. REPLACED AFTER CANNIBALIZATION. THIS CODE IS ENTERED WHEN AN ITEM OF MATERIAL IS REPLACED AFTER CANNIBALIZATION.

Y. TROUBLESHOOT. THIS CODE IS USED WHEN THE TIME EXPENDED IN LOCATING A DISCREPANCY IS GREAT ENOUGH TO WARRANT SEPARATING THE TROUBLESHOOT TIME FROM THE REPAIR TIME. USE OF THIS CODE NECESSITATES COMPLETION OF TWO SEPARATE DOCUMENTS, ONE FOR THE TROUBLESHOOT PHASE AND ONE FOR THE REPAIR PHASE. WHEN RECORDING THE TROUBLESHOOT TIME SEPARATE FROM THE REPAIR TIME, THE TOTAL TIME TAKEN TO ISOLATE THE PRIMARY CAUSE OF THE DISCREPANCY IS RECORDED ON A SINGLE FORM USING THE SYSTEM, SUBSYSTEM, OR ASSEMBLY WUC AS APPROPRIATE.

Z. CORROSION TREATMENT. INCLUDES CLEANING, TREATING, PRIMING AND PAINTING OF CORRODED ITEMS THAT REQUIRE NO OTHER REPAIR. THIS CODE IS ALWAYS USED WHEN ACTUALLY TREATING CORRODED ITEMS, EITHER ON EQUIPMENT OR IN THE SHOP. USE SUPPORT ACTION FORM AND APPLICABLE CODE WHEN REPORTING PAINTING OR CORROSION PREVENTIVE TREATMENT.

0. THE NUMERIC 0 WILL BE USED IN THE ACTION TAKEN BLOCK ON ALL SOURCE DOCUMENTS RECORDING LOOK PHASE MAN-HOURS FOR ACCEPTANCE/TRANSFER, CONDITIONAL AND CALENDAR INSPECTION, INCLUDING THE CLOSE OUT OF MAN-HOURS ON THE LOOK PHASE OF THOSE INSPECTIONS AT THE END OF THE REPORTING PERIOD.

NOTE: THE ACTION TAKEN CODES D, E, J, K, AND R ARE NOT USED IN BLOCK 11 (ACTION TAKEN CODE) ON THE SINGLE-COPY MAF.

The tasks described below are those recommended for accomplishment during the Phase II Study.

Task I - Sample Determination

The following aircraft T/M/S and associated WUCs will be the subjects of the Phase II study:

- F-14A, WUC 74
- F-4J, WUC 74
- S-3A, WUCs 13 & 73

From the standpoint of the quantity of data to be processed, those operational sites with the minimum number of aircraft will be identified for each T/M/S. To avoid the need to track equipment across aircraft of different T/M/S at a common site, those equipments which are peculiar to the subject aircraft at each site will be selected.

Task II - Site Visits

In order to obtain information which is not furnished by hard data, several field visits will be made. In particular, the following types of information will be acquired via visits to the associated organizations:

- Depot(s) for the proportion of equipments received which are not defective
- AIMD(s) for the proportion of ATC 1-8 actions not bench-tested to verify failure if preceding visits reveal a significant no-defect rate at the depot
- Organizational, intermediate, and depot maintenance activities, as necessary, to verify and/or identify physical and functional relationships among equipments

Task III - Physical and Functional Relationships

Identification will be made of those WUCs, maintenance of which can result in Maintenance-Induced Defects and False Alarms due to inefficient diagnosis. Matrices will be developed which will display the subject WUCs affected by each causative WUC.

Technical manuals utilized by organizational, intermediate, and depot level personnel will be obtained and analyzed for this purpose. In addition, the site visits conducted under Task II will be utilized to verify and identify, as necessary, the physical and functional relationships associated with the subject WUCs.

Task IV - Model Refinement

The models available for estimating the cost impact of unnecessary maintenance actions will be identified as part of this task. The modifications required to adapt each of these models to satisfy the objectives of the Phase II study will be determined and the applicable refinements will be made.

Task V - Software Development

Since the AMPCS system creates a magnetic tape in output format for each report requested by the user, computer software will be developed which will utilize such tapes, as input, to identify and quantify, for the selected T/M/S and WUCs, the occurrences of unnecessary maintenance actions. Report No. PTX 438D will be utilized for this purpose. The software will also be capable of identifying the MMH and NOR time associated with each such action. Report Nos. PTX 438E and 438P will be

utilized, respectively, for this purpose. In addition, the cost models developed under Task IV may, if deemed advantageous, be incorporated into the software. The input data required for cost estimation will be assembled under this task.

For the purposes of debugging and execution (addressed under Task VI), the requisite AMPCS output tapes will be requested for all of the selected T/M/S and WUCs during the flowcharting/coding/keypunching portion of this task. Identification of the physical and functional relationships (to be treated as input matrices) will also be completed at that time.

It is also anticipated that, for debugging and execution purposes, use of a computer facility which is capable of reading and interpreting the above-mentioned AMPCS tapes will be provided by the Government.

Task VI - Data Processing

Upon completion of Task V, the software developed under that task will be executed for all of the selected T/M/S and their selected WUCs. The output will be a hard-copy summary of the number of unnecessary maintenance actions of each type, and their associated resources (e.g., MMH) and downtime impact.

Task VII - Analysis

Upon completion of Task VI, the output data and cost models developed under Task IV, as necessary, will be utilized to estimate the cost impact of unnecessary maintenance. The resulting data will be tabulated to provide comparisons among selected aircraft WUCs by problem area and by cost element, as well as at an aggregate level.

Additionally, an analysis will be made regarding BIT effectiveness of selected equipments on the S-3A, as compared to other equipments considered by this study which do not contain BIT.

Task VIII - Report

Upon completion of Task VII, a draft report will be prepared. This report will detail the results of Tasks I through VII. It will include the information obtained from site visits and maintenance manuals, the physical and functional relation matrices, the cost models formulated, a flow chart and program listing for the software implemented, and the results of data analysis conducted under Task VII, including the comparative analysis of BIT.

Upon submittal of the Draft Final Report, the Government shall be allowed 15 days for review. After receipt of comments regarding the Draft Final Report, the report will be resubmitted to the Government in Final form within 15 days.

Recommended Milestone Schedule For Phase II

Figure C-1 presents a recommended milestone schedule for Phase II. This recommended milestone schedule is predicated upon initiation of Phase II during mid-April 1978. It should further be noted that in order for this schedule to be satisfied, the technical manuals required under Task III must be made available no later than 1 May 1978, and that access to AMPCS data required under Task V be provided no later than 1 July 1978. If these requirements can not be satisfied, the recommended milestone schedule would have to slip to the right accordingly.

Figure C-1. Recommended Milestone Schedule for Phase II